POTENTIAL OF THE NEW ZEALAND FOREST SECTOR TO MITIGATE CLIMATE CHANGE

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Abstract

New Zealand is both an Annex I Party to the UNFCCC, and an Annex B country of the Kyoto Protocol. By ratifying the latter, NZ has committed to reduce greenhouse gas emission to 1990 levels. The country should take domestic actions and can also use any of the Kyoto Protocol flexible mechanisms. Afforestation and reforestation on low carbon density land has been recognised as a carbon sink and hence a possible mitigation option for climate change. The current situation for New Zealand is that at least over the first commitment period (2008-2012) the country is in deficit, because emissions have continued to grow over the 1990 level, there is an increase in the deforestation rate and lower rates of new planting.

The objective of this study is to analyse the potential of the New Zealand forest sector as an integrated system to mitigate climate change. It also analyses the impact of different mechanisms on potential area of new land planting, management of stands, and the supply, allocation, and demand of wood, and wood products.

The New Zealand forest industry carbon balance (i.e net atmospheric exchange minus emissions) is modelled for different national estate scenarios, log allocation of harvested volume and residues used for bioenergy. The net present value of these scenarios is estimated and the economic viability assessed. The level of incentives needed to increase the returns to an economically viable level is estimated in term of carbon unit value ($/tC). Moreover the land use economics at a project level (land market value vs land expectation value) is assessed. Incentives needed in monetary terms and carbon value are also estimated. The implications of discounting carbon benefits are discussed.

It was found that the carbon balance of the whole industry should be analysed for policy development on climate change mitigation options. New planting, longer rotation ages, avoiding deforestation, and allocating additional harvested volume to sawmills showed positive impact to the atmosphere. New planting appeared to be not economically viable, thus incentives are needed. It is acknowledged that, there are emissions from the sector that were not included, and that data and models used need further research to improve the

accuracy of the results. Moreover, assumptions on the economic issues and an analysis of simultaneous implementation of more than one mitigation option would also improve the results.

CHAPTER 1. Introduction

There is now vast scientific evidence showing that climate change presents serious global risks and that a global response is needed The impacts of today's actions on the future can have a profound effect on the climate over the next years. These consequences cannot be predicted with certainty, but mitigation, taking strong actions to reduce emissions and sequester carbon, can be viewed as an investment to reduce the difficulties of adapting to climate change in the future.

The stocks of greenhouse gases (GHG) in the atmosphere are rising as a result of human activities. The annual emissions to the atmosphere continue to increase as economies are growing and demand for energy and transport increases around the world. Global emissions for 2000 by sectors were: 24% from power, 14% from industry, 14% from transport, 8% from buildings, 14% from agriculture, 18% from land use, 3% from waste, and 5% from other energy related activities.

Net carbon emissions can be reduced through mitigation strategies and policies that lead to emission cuts and promote carbon sequestration. There are different ways to achieve this with different costs, depending on which combination is taken in which sector. Emission reduction can be achieved by reducing the demand of emission intensive goods and services, improving efficiency, avoiding deforestation, and substitution of fossil fuel with lower carbon technologies. Energy efficiency has the potential to be one of the most important sources of emission savings in the energy sector, having the environmental benefit of reducing waste and also reducing costs. Non-energy emissions (i.e from land use, agriculture and waste) make up more than one third of global emissions. Other types of mitigation that must be taken into consideration are to: (i) avoid deforestation, (ii) reduce and use of waste and (iii) increase sequestration rates. Higher carbon sequestration rates can be achieved by a combination of land use and forest management strategies such as increasing forest area, changing forest rotation length and altered silviculture.

In the last decade actions have been taken internationally to reduce the level of GHG in the atmosphere. The United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol (KP) are two international agreements that deal with global climate change. New Zealand is both an Annex I Party to the UNFCCC and an Annex B country of the KP. The UNFCCC was negotiated in 1992 to stabilise greenhouse gas concentrations at a level that avoids dangerous human interference with the climate system. It entered into force in 1994. The KP was a further agreement negotiated in accordance with the convention and signed by 170 countries during the third conference of the parties (COP3) in December 1997. Parties to the KP have committed to reduce their GHG emissions on average to 5% below the levels of 1990 in the commitment period 2008-2012 (UNFCCC 1997). The KP came into force in February 2005.

Under these frameworks, emission reports are presented and analysed by sectors (i.e power, industry, transport, buildings, agriculture, land use, waste, and other energy related). Therefore, the carbon flow between sectors and the implications of taking actions in one of them is not considered holistically. The forest industry has the potential to mitigate climate change through emission reductions from energy use, energy efficiency, waste management and enhanced carbon sequestration rates. The net atmospheric exchange of the industry is a complex issue that needs to be looked at when designing forest, energy, waste and climate change policies. Policies are required to support the development of a sustainable forest industry and help achieve a positive carbon balance by affecting these factors. The identification of factors and the way in which they affect the net atmospheric exchange (NAE) of the industry is the approach followed in this report. This will be done by looking at the lifecycle of wood products.

The following sections describe the forest sector and present an overview of the New Zealand land use change and forestry (LUCF) greenhouse gas inventory, the national forest estate, the wood processing industry and its energy use. New Zealand climate change policy aiming at addressing these commitments is then introduced. Finally, the research issues and objectives of the study are presented.

1.1 New Zealand LUCF GHG Inventory, the National Forest Estate and Forest Industry.

The Intergovernmental Panel on Climate Change (IPCC) established the guidelines for National Greenhouse Gas Inventories, and defined the categories that should be used when reporting greenhouse-gas (GHG) emissions and removals. Source and sink categories were grouped as follows: energy; industrial processes; solvents and other product use; agriculture; land use change and forestry (LUCF); and waste (IPCC 1996).

1.1.1 Land Use, Land Use Change and Forestry GHG

New Zealand's total GHG emissions in 2003 equalled 75.3 million tonnes of CO2 equivalent (Mt CO2e) and were 22.5% above the 1990 level. The agriculture sector produced 37.2 Mt CO2e or 49.4% of total emissions in 2003. Emissions in this sector are now 15.6% or 5 Mt CO2e over the level in 1990. The energy sector produced 32.3 Mt CO2e or 42.9% of total emissions in 2003. Emissions from the energy sector are now 37.0% or 8.7 Mt CO2e above the 1990 level (Ministry for the Environment 2005).

The most recent and likely estimate of average annual emissions (Ministry for the Environment 2005), including all associated policy effects, during 2008-2012 is 80.9 Mt CO2e per annum. The projected removal units based on national radiate pine and for the most likely scenario was 70.9 Mt CO2e Over the first commitment period. This represents a net deficit of 36.2 Mt CO2e over the five year period (i.e first commitment period of the Kyoto Protocol). The expected value of emissions from deforestation remains the historical (2-3%) rate of deforestation. This equals a loss of 6.3 Mt CO2 under the most likely estimate. The minimum amount of deforestation is also set to 6.3 Mt CO2. The impact of rotation age is most relevant after the first commitment period.

At present, there is considerable uncertainty in the data on carbon stocks and carbon stock changes for forest land. The available data suggest that carbon stocks are likely to be in a steady state or a slight decline. An assessment of the significance to New Zealand of Article 3.4 forest management activities concluded that the balance lay somewhere between -92 Mt CO2e to 11 Mt CO2-equivalent over the first commitment period (Ministry for the Environment 2005).

1.1.2 National Forest Estate

New Zealand's planted production forests covered an estimated 1.82 million hectares as at 1 April 2004. Seventy percent of the forest area is in the North Island and 30 percent is in the South Island. Thirty-two percent of the entire planted forest estate is in the Central

North Island wood supply region. Other significant forest resources are in the Northland, Nelson-Marlborough and Otago-Southland regions (see Appendix III and IV).

Radiata pine (*Pinus radiata D. Don*) is the dominant species, making up 89 percent of the planted forest area, with Douglas-fir (*Pseudotsuga menziessi Mirb. (Franco*))the next most common species, making up 6 percent. The balance comprises other softwood and hardwood species (MAF 2005c).

MAF (MAF 2005c) estimated 19,900 hectares of new forest were established in 2003. Twenty eight percent of this planting occurred on improved pasture, 26 percent on land where scrub was previously the predominant land cover and 46 percent on unimproved pasture. It is provisionally estimated that 10,600 hectares of new planting occurred during 2004.

The average new planting rate over the last 30 years has been 44,000 hectares per year. In the period 1992 to 1998 new planting rates averaged 69,000 hectares per year. However, since 1998 the rates of new planting have declined. At 10,600 hectares in 2004, new planting is now well below the average afforestation rate of the last 30 years (MAF 2005c).

Between 1990 and 2003 it is estimated that 660,000 hectares of new forest have been established. New entrants to forestry have carried out much of this new planting. While these new owners have planted a significant area during the 1990s, 71 percent (1.3 million hectares) of the entire forest resource is still currently owned by growers with more than one thousand hectares of forest.

Significant areas of forest established in the 1970s are now maturing and are expected to be harvested over the next decade. NEFD National and Regional Wood Supply Forecasts (MAF 2000) presents the details about these forecast increases in harvest levels.

The relatively new trend of not replanting forest after harvesting, and converting immature forest to pasture, has started on a larger scale over the last 2 to 3 years. Historically little conversion of planted production forest land has occurred. It is understood that approximately 10,000 hectares of planted forest has been converted to pasture between 2002 and 2004.

An estimated 19.4 million cubic metres of roundwood were harvested from New Zealand's planted production forests in the year ended 31 March 2004. An estimated 18.6 million cubic metres came from clear felling 40,800 hectares of planted forest, and 0.8 million cubic metres from production thinning. About 38,200 hectares of previously clear felled planted forest were replanted in 2003 (MAF 2005c).

1.1.3 Wood Processing Industry and Energy Use

The wood industry sector consists mainly of sawmilling, pulp and paper and panel producers. The largest energy consumer (68% of the total or 71% including geothermal) is the pulp and paper sector. The sawmilling and panel sectors consume 19% and 13% respectively (Anderson *et al.* 2003).

The wood processing sector of the forest industries uses an estimate of around 69 PJ per year of total primary energy (around 10-11% of total energy use in NZ), including electricity and geothermal. Wood processing residues and black liquor accounts for 36.6 PJ of the total, indicating that the industry supplies over 50% of its own energy. Electricity and natural gas use represents around 18% and 17% respectively. Geothermal steam is also used, being approximately 6.9 PJ, making up almost 10% of total energy use in the sector.

The survey conducted in 2002 (Anderson *et al.* 2003) indicates that energy uses increased by 40% over the last five years. The increase is attributed to sawmill out-turn and panel production. The sawmilling sector increased energy use between 1997 and 2002 from 2.77PJ to 8.1 PJ. Production only increased from 3 million m^3 to 3.8 million m^3 suggesting the increase is largely due to an increase in kiln drying and finishing. The panel sector has expanded to around 8.4 PJ, and within it, the use of biomass for energy has increased by over 5PJ.

1.2 New Zealand Climate Change Policies and Mechanisms and their Implications for the Forest Industry

The New Zealand Government's climate change policy package was approved in October 2002 (Ministry for the Environment 2005), building on existing policies and strategies

(National Energy Efficiency and Conservation Strategy; the New Zealand Transport Strategy; the New Zealand Waste Strategy; the Growth and Innovation Framework; and the Sustainable Energy work programme within the Sustainable Development Programme of Action). A range of broad non price-based measures were introduced such as the development of business opportunities and public awareness. Non-price-based measures focusing on particular sector emissions were also introduced to encourage emissions reduction and adaptation to the effects of climate change. Specific sectors identified include the agriculture sector, forestry sector, local government, small and medium enterprises, synthetic gas users.

The policy package required the provision of annual reports and reviews in 2005, 2007 and 2010. In June 2005, after the projections of New Zealand's greenhouse gas emissions during the Kyoto Protocol's first commitment period (2008-2012), the policy was reviewed. The Review identified options for New Zealand climate change policies up to 2012 and beyond. It also looked at the implications for New Zealand if current, alternative, or additional climate change policies were adopted. As a result, the Government decided not to implement a carbon tax, or any other broad based tax, in the first commitment period under the Kyoto Protocol. The New Zealand climate change policy package (New Zealand Climate Change Office 2002) implemented the following mechanisms: (i) 'Negotiated greenhouse gas agreements' (NGA); (ii) The 'Projects to Reduce Emissions'. They are suspended, while work programmes are being evaluated.

The Government of NZ proposed a "permanent forest sink initiative'' (PFSI) for the forestry sector to incentivise permanent (non-harvest) "commercial" forest sinks (New Zealand Climate Change Office 2004a) . The criteria of the policy design were, among others, to be consistent with the Kyoto Protocol, Marrakech Accords and Good Practice Guidance on accounting for land use, land use change and forestry activities. The PFSI also aimed at providing efficient market signals to landowners; and clear separation between forests established for timber production and those established for carbon sequestration. It was also intended to achieve environmental benefits in terms of enhanced biodiversity, reduced soil erosion, and improved water quality and some reduced agricultural emissions; while minimizing compliance and administrative costs (New Zealand Climate Change Office 2004b). The public policy objective was to contribute to New Zealand's response to climate change by encouraging additional sequestration of carbon by forests and encourage the development of a trading market for greenhouse gas emission units and to reward those who establish new permanent forests.

Establishing permanent forests would gain fully tradable Kyoto Protocol compliant emission units. The emission units generated are equal to the increase in CO_2 stored in a given area of forest between 2008 and 2012.Landowners will meet all costs associated with generating the emission units and agree to 'replace' any units, if the carbon stored in the forest is released back into the atmosphere again. Eligibility into the PFSI requires adherence to Kyoto Protocol rules regarding the land that would qualify, the definition of a forest, and the definitions of afforestation and reforestation activities.

As part of a series of work programmes on climate change policy, the Government is considering other forestry policy options related to managing deforestation; encouraging afforestation (new forest establishment); and land-use and the links between forestry and agriculture policies (land-use change). For the agriculture and forestry sectors the focus will be on research to reduce emissions from livestock and agricultural practices; measures to address the trend to harvest trees (and not replant); and the development of measures to encourage new plantings.

The development of incentives for appropriate research and uptake of new technology with emphasis on agricultural practices, energy production and use is also included in the work programmes under consultation.

The climate change policy programmes also include proposals and strategies in energy and transport, increasing the use of renewable energy; being more efficient with the use of energy; looking at alternatives to the carbon tax; and cross-sector initiatives. The New Zealand Energy Strategy to 2050 (NZES) and The New Zealand Energy Efficiency and Conservation Strategy (NEECS) are part of climate change policy development which make up the climate change energy sector work programme to reduce energy-related greenhouse gas emissions.

Particularly relevant to the forest sector was the National Energy Efficiency and Conservation Strategy (NECS) that has established the renewable energy target (EECA

2001b). It is a package of policy measures and targets that aims to improve energy efficiency by 20 per cent and increase renewable energy sources by 30 PJ by 2012. There are two Government proposals being revised that will eventually replace the NEECS. One of them is The New Zealand Energy Strategy to 2050 (NZES) that will focus on the long-term strategic direction for a sustainable low emission energy system. Moreover, The New Zealand Energy Efficiency and Conservation Strategy (NZEECS) will focus on how energy demand is managed into the future, and is an action plan to maximise energy efficiency and renewable energy.

The climate change policy and associated mechanisms will affect the New Zealand forest industry through the PFSI initiative, any mechanisms adopted from the ‘’Sustainable Land Management and Climate Change’’ options, NEECS, and NZES , The decision of the New Zealand government to retain sink credits also has an impact. Negotiations on harvested wood products (HWP), exemptions for competing land uses and products may in turn also affect the GHG balance of the industry.

In order to analyse the implications of climate change policies on the potential of the New Zealand forestry sector to mitigate climate change, the GHG balance of the land use, land use change and forestry sector (LULUCF), the processing industry and wood products should be taken into consideration. Matthews and Robertson (2002) reviewed policy level models and concluded that (i) carbon sequestration in forests is important until carbon saturation occurs; (ii) wood products make only a small contribution to the carbon balance with only short term effects; (iii) the use of wood products to cut emissions at source through substitution of fossil fuel has the largest potential impact. Similar conclusions were reached by Ford-Robertson (1996).

The interactions between policies and the forest industry carbon balance are illustrated in Figure 1. Policies or instruments that affect forest plantations, such as areas of new planting, species, and rotation age, will in turn affect the national forest estate and the resources available for processing. The national forest estate can be a source or a sink of carbon to the atmosphere, thus directly affecting the carbon balance. Additionally, the forest estate is linked to the processing industry that will process these resources, and affect the volume that will be exported, and the amount of residues that can be disposed of to landfills or used to produce bioenergy. Emissions in the sector arise from harvested wood through energy use and decay of wood products, as well as from management operations, harvesting and transport, and processing.

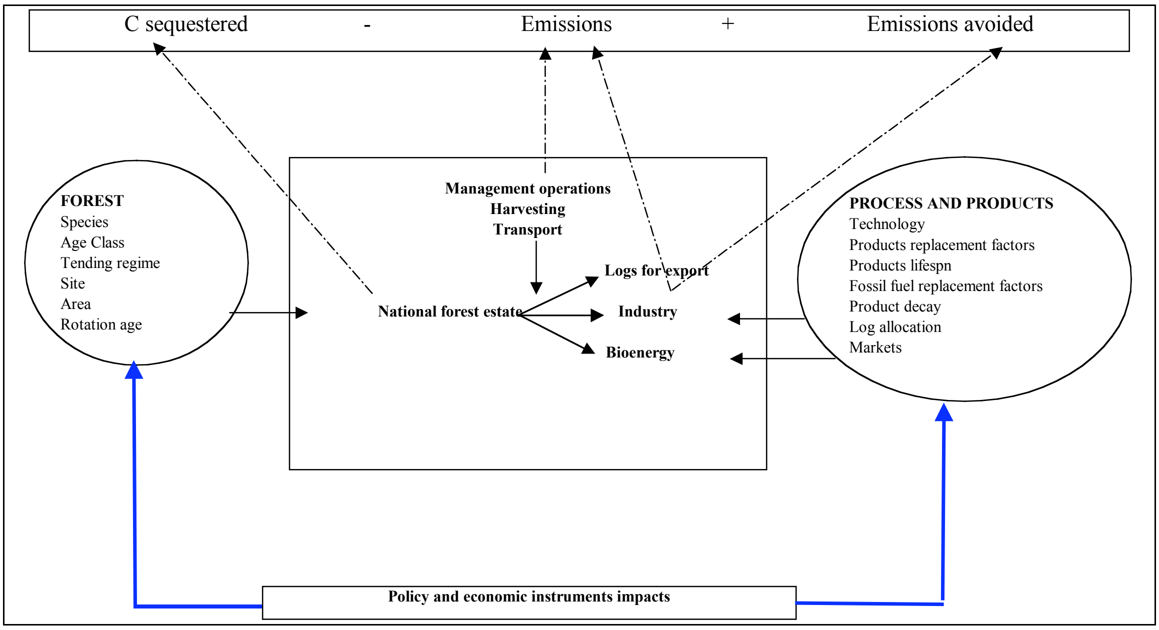

Figure 1. Factors affected by climate change policies and economic instruments.

Policies such as emission charges to the industry and transport, incentives to increase renewable energy use, charges or other environmental regulations on landfill disposal, will affect the carbon balance. Other issues related to the accounting for carbon emissions or sequestration may also change the results of the carbon balance of the system such as international policy negotiations on harvested wood products accounting, and default factors to use in the accounting. Increasing and encouraging transfer of technology and research and development on different areas might change and improve the estimations and change the carbon balance results as well. In the processing sector technology and efficiency has an impact on conversion factors for the plants, energy intensity of products, and emission factors. Estimates of harvested wood products lifespan and decay rate, and replacement factors when wood products substitute more energy intensive products such as concrete or steel are all relevant and ultimately influence the balance.

1.3 Research Issues

This study evaluates a number of research issues:

1. **Forest management and carbon balance.** Various factors must be considered in order to analyse the impact of climate change policies on the carbon balance, and

hence, the potential of the sector to mitigate climate change. In order to analyse these impacts or benefits of forests on the carbon balance, the industry as a whole (i.e plantations, processing industry and wood products) need to be assessed as an integrated system. Sensitivity analyses can be performed on different variables such as (i) the rate and proportion of new land planting, rotation age, species selection and tending regimes, (ii) proportions and decay rate of residues left on site, (iii) demand for wood and allocation of logs, (iv) proportion of energy consumption substituted by bioenergy, and (v) product and fossil fuel replacement factors. The national forest estate needs to be assessed in terms of carbon balance and financial factors to determine the need to encourage participants to achieve the desired outcomes.

2. **Mechanisms**. Different mechanisms need to be evaluated to identify: (i) what mechanism would be used to achieve target afforestation rates, and how would these be linked back to assess the impact on target sequestration rates (ii) what criteria might be put on any afforestation incentives to ensure target desired mitigation options are adopted (iii) what other mechanisms could be used to encourage afforestation or otherwise improve the carbon balance of the forest and processing industry.
3. **Potential of the forest industry to help meeting renewable energy target**. The future forest estate could be seen as a 'new forest' that can feed a completely new processing sector that could also play an important role meeting the renewable energy target proposed by the Government by increasing renewable energy use such as processing residues for bioenergy.
4. **Emissions avoided through fossil fuel substitution.** The residues from plantations and processing plants has energy potential and if used for energy that substitutes fossil fuel use there are emissions that are avoided. These variables have a direct impact on energy use that will affect the carbon balance and hence, the benefits of the sector.
5. **Economics of carbon sequestration projects.** A number of methodological aspects of the economics of carbon sequestration are still a matter of debate and thus require further research. These methodological aspects include the definition of appropriate discount rates when carbon is considered as another environmental benefit of forests and not only as another market value.

1.4 Objectives

The main objectives of this study are:

1.4.1 General Objectives

To analyse the potential of the forest sector as an integrated system to help mitigate climate change, and the impact of different mechanisms on potential new land planting area, management of stands, and the supply, allocation, and demand of wood, and wood products.

1.4.2 Specific Objectives

1. To estimate the carbon balance of forest plantations (i.e. *Pinus radiata*, *Pseudotsuga menziessii,* hardwoods and other softwoods in New Zealand) and the forest industry as an integrated system (i.e. carbon net atmospheric exchange of forest plantations, and emissions from wood processing sector and wood products).
2. To identify the level of incentive necessary to have an impact on new planting area and increase sequestration, reduce emissions from deforestation, and to improve the economic returns of forestry projects. The national level carbon balance will be the main indicator of the impacts.
3. To identify mitigation options through land use management, forest industry and bioenergy aimed at reducing GHG emissions for the short and long term.
4. To analyse the potential of the forestry sector to increase the use of woody biomass (residues from wood processing) for bioenergy which would help meeting the renewable energy targets.
5. To analyse the impact of emissions avoided on the carbon balance when biomass substitute fossil fuel.
6. To investigate the use of discount rate on the economic analysis of carbon benefits as an environmental and market value of forest.

1.5 Thesis outline

Policy instruments, that provide incentives to the forest sector, would affect the management of forest plantations and the national forest estate and hence the wood processing industry. Those factors affected by the policy will in turn alter the carbon balance of the whole sector through land use change, processing emissions or energy use and emissions from harvested biomass.

The carbon balance of the national forest estate, forest industry and harvested wood products as an integrated system will be analysed in order to identify whether they meet the aim at reducing GHG emissions.

The analysis in Chapter 2 is based on the carbon balance (i.e net atmospheric exchange in the forest minus emissions)[1] of different national forest estate scenarios. The net present value of these scenarios is estimated and the economic viability is assessed. The level of incentives needed in order to increase the return and become economically viable is estimated. The value of carbon unit necessary to meet this level of incentives is also estimated.

Chapter 3 looks at the impact of log allocation and an increase in the use of processing residues for bioenergy on the balance and hence whether they can be considered as climate change mitigation options. Other benefits of bioenergy such as emissions avoided through fossil fuel substitution will be discussed.

An analysis of the land use economics at a regional level is presented in chapter 4. The question of whether incentives granted to individual projects are needed to encourage land use change to forestry, is investigated. The level of incentive necessary to achieve this change is analysed in economic terms (i.e land expectation value vs land market value). The results of this analysis are compared to the carbon balance at the national level.

In chapter 5 the implications of different discount rates on the carbon benefits as well as options to address these controversial issues are discussed.

[1] The sign protocol for carbon balance says that emissions/sources are positive and removals/sinks are negative. Throughout this report, a negative carbon balance means emissions are higher than net atmospheric exchange, and positive balance means the net atmospheric exchange is higher than emissions.

Finally, Chapter 6 summarises the main conclusions, their implications to the forestry sector in New Zealand, and also presents key areas for further research.

CHAPTER 2. Carbon Balance of the Forest Industry

This chapter presents a review of factors affecting the carbon balance, methodologies for budgeting carbon and the approach to estimate the carbon balance of the NZ forest industry using the following steps:

(i) estimation of the net atmospheric exchange for the national forest estate;
(ii) estimation of log allocation and products from the forest industry;
(iii) estimation of emissions from the forest processing industry; and
(iv) estimation of emissions from forest residues, harvested wood products (HWP) and processing residues;

Estimates are then applied in a comparative analysis of different forest estate scenarios.

2.1 Factors affecting Carbon Balance

Various factors must be considered in order to analyse the impact of climate change and renewable energy policies on the carbon balance (Matthews 1996). These include: (i) the current status of the land, (ii) expected productivity following land use change; (iii) efficiency in the use of forest products substituting fossil fuels or other products; and (iv) the time frame considered in the analysis (Marland and Marland 1992). Forest productivity depends on the species planted, and hence the carbon balance of a site is sensitive to species selection. The lifespan of products in relation to the growth rate and rotation age of a forest also affects the carbon balance of a system thus representing another factor to be considered when selecting climate change mitigation strategies. However, most analyses to date incorporate the 'instant oxidation' assumption and therefore do not result in any preference for releasing the sequestered carbon over a longer time period.

Carbon balance can be derived from the flows alone, and the net flow can be reported as a stock change or vice-versa (the difference between two stocks equals net flow). To obtain a complete representation of what is happening both the stocks and flows should be identified.

The IPCC Guidelines (IPCC 1996) state " the net flux to or from a particular site will always be reflected in the change of carbon stocks on site and/or in the products pools associated with the site. Thus, a methodology that determines carbon stock changes also provides estimates of the net fluxes of CO2" (IPCC 1996). Hence, the different carbon stocks to be accounted for include: (i) soils and vegetation under current land use (i.e. before planting), (ii) aboveground and belowground biomass of the forest and (iii) wood products.

There is a flow of carbon to the atmosphere (i.e carbon emissions) resulting from land use change to forestry due to: (i) emissions from land preparation for planting (e.g. vegetation clearance, weed control, soil emissions from the mineralisation of organic matter) (ii) emissions from fossil fuel use during planting, management operations and transport (iii) emissions from residues left on the ground after silvicultural and harvesting operations (i.e. decay of forest residues), (iv) emissions from wood processing (i.e. energy) and (v) emissions from product decay and waste from processing plants (i.e. processing residues).

As a result of afforestation certain flows of carbon to the atmosphere can also be reduced or avoided such as: (i) emissions from previous land use (e.g. pasture) including nitrous oxide and ruminant methane, (ii) emissions from the production of non-wood products through product substitution (iii) fossil fuel emissions through substitution with bioenergy.

2.2 Carbon Balance Methodology

Marland *et al.* (1997) points out that the magnitude of carbon benefits depends on the growth rate of the forest, the efficiency of the use of wood products, and fossil fuel substitution. Land use prior to afforestation also affects carbon reduction benefits. Some studies suggest that managing forest for sustainable timber production could sequester more carbon than management with no interventions. Marland and Marland (1992) suggest that for high productivity sites, the best strategy would be to manage the forest efficiently to produce long-lived wood products and/or to substitute fossil fuels. Cannel (1984) points out that if the lifespan of the wood products is shorter than the time taken to reach maximum Mean Annual increment (MAI), it is not worth harvesting that forest if carbon sequestration is the main objective. Marland *et al.*(1996) also suggest that the sustainable harvest of forest with high growth rates combined with the efficient use of wood products is favourable over the total protection of standing forest to sequester carbon.

Marland *et al.*(1997) suggests that if the objective is to reduce GHG emissions a way to maximize the use of wood to cut fossil fuel consumption should be found. This suggests that if the goal is to reduce carbon emissions then the aim should be to cascade biomass use, managing high forest stocks to produce dense, durable timber that can maximise product substitution in long-lived applications, be reused/recycled, and finally be used as a fuel.

Models are needed to evaluate the benefits of carbon sequestration, indirect and direct fossil fuel substitution and the impact of forestry and wood use policy options aimed at maximizing GHG emission reductions. The outputs of such models, will contribute to the development of appropriate forestry policies and accounting systems. Product replacement factors, emissions avoided, and the decay rate of products at end are all important aspects affecting the carbon balance.

The carbon balance of the entire forest industry can be modelled with sensitivity analyses performed on different variables such as (i) the rate and proportion of new land planting, rotation age, species selection and tending regimes, (ii) decay rate of residues left on site, (iii) demand for wood and allocation of logs, (iv) proportion of energy consumption substituted by bioenergy, and (v) product and fossil fuel replacement factors.

2.3 National Level Carbon Balance Model

The forest industry carbon balance (Figure 2) equates to the net atmospheric exchange (NAE) of forest plantations minus the emissions from processing plants, wood products and residues.

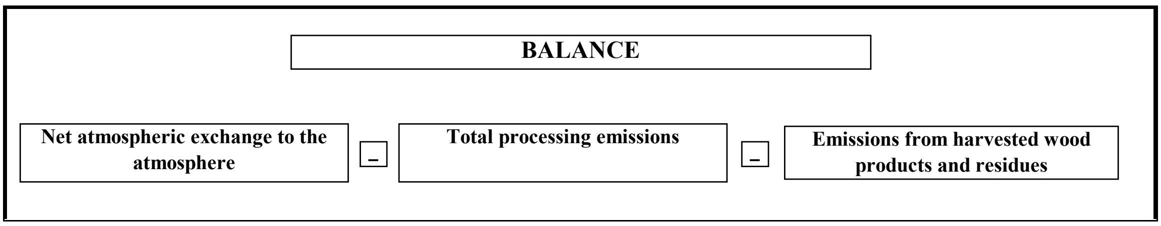

Figure 2. Carbon balance of the forest industry.

Seven croptypes were selected[2] to represent the national forest estate of New Zealand as the first step to estimate net atmospheric exchange. The seven croptypes were selected based on the national yield tables (MAF 1995) and on Robertson *et al.* (2001). They are widely used in New Zealand for forest statistics are the same as those used for national reporting in the National Exotic Forest Description (NEFD), and for analyses of the forest industry, as they give a fair representation of the national forest estate allowing national level studies.

Yield tables for volume and carbon were generated using the STANDPAK C_change model (Beets *et al.* 1999). STANDPAK is a computer-based stand modelling system, used to predict volume, size, and quality of logs from stands grown on a range of sites in New Zealand, Australia, and Chile, and managed under a wide range of silvicultural regimes (Whiteside 1990; West 1993). The Stand Growth module of STANDPAK estimates gross and net stem total volume under bark (among other things), given management information specific to a particular stand. This allows the calculation of stem volume growth and mortality. A number of empirical growth models have been included in the Stand Growth module[3] of STANDPAK, allowing growth predictions to be made for different growth regions. These regional growth models are derived from data from a nationwide network of over 23 000 permanent sample plots. The data inputs and resulting growth predictions of the Stand Growth module are required by the Growth Partitioning module (stand age, volume, height, basal area, pruned height, stocking, harvest removals) for predicting stand carbon content. Hence, the Growth Partitioning module has been linked with the Stand Growth module, and together they are referred to as C_change.

C_change of STANDPAK (Beets *et al.* 1999) allows the simulation of the carbon content for radiata pine and other species at a stand level over two rotations, assuming the same management regime throughout. It assumes that slash and forest floor carbon from the first rotation becomes the initial carbon stock for the following rotation. Dead trees and branches as well as trees from thinnings are transferred to the forest floor where they decompose. Litter decay rates determine the rate at which carbon is released from the stand

[2] The radiata pine regimes used were pruned with production thinning, pruned without production thinning, unpruned with production thinning and unpruned without production thinning. Robertson *et al* (2001)

[3] The models used for Pinus radiata estimations was 'Med 0' and 'PPM 88', for Douglas fir was Dfir 'SPAPBA 3001 Med 6.7' and 'nitens' growth model was used for hardwoods.

to the atmosphere. According to (Beets *et al.* 1999), annual average decay rates of needles, fine roots and stems are 0.22, 0.52, and 0.18 respectively. Based on these rates the decay rate of branches was assumed to be midway between those of needles and stem. These decay rates were used to estimate emissions from forest residues to the atmosphere as part of the NAE in forest (see Section2.3.5).

Table 1 shows seven crop types defined for radiata pine, Douglas-fir, hardwoods and other softwoods, and Figure 3 and Figure 4 show total recoverable volume (TRV) and mean annual increment (MAI) for the selected croptypes. Appendix I presents the total recoverable volume yields and the mean annual increment for each croptype.

Table 1. Silvicultural regimes assumed for the seven croptypes.

Croptypes	Species	Initial stocking (Stems per hectare)	Pruning age (years)	Thinning age (Years)	Stems per hectare after thinning
1	Pinus radiata	1200	6 8 9	6 9	400 250
2	Pinus radiata	1200	6 8 9	6 12	600 200
3	Pinus radiata	1500		6	400
4	Pinus radiata	1500		6 14	600
5	Hardwoods	1100			200
6	Douglas fir	1600		15	500
7	Other softwoods	1500		6 14	600 200

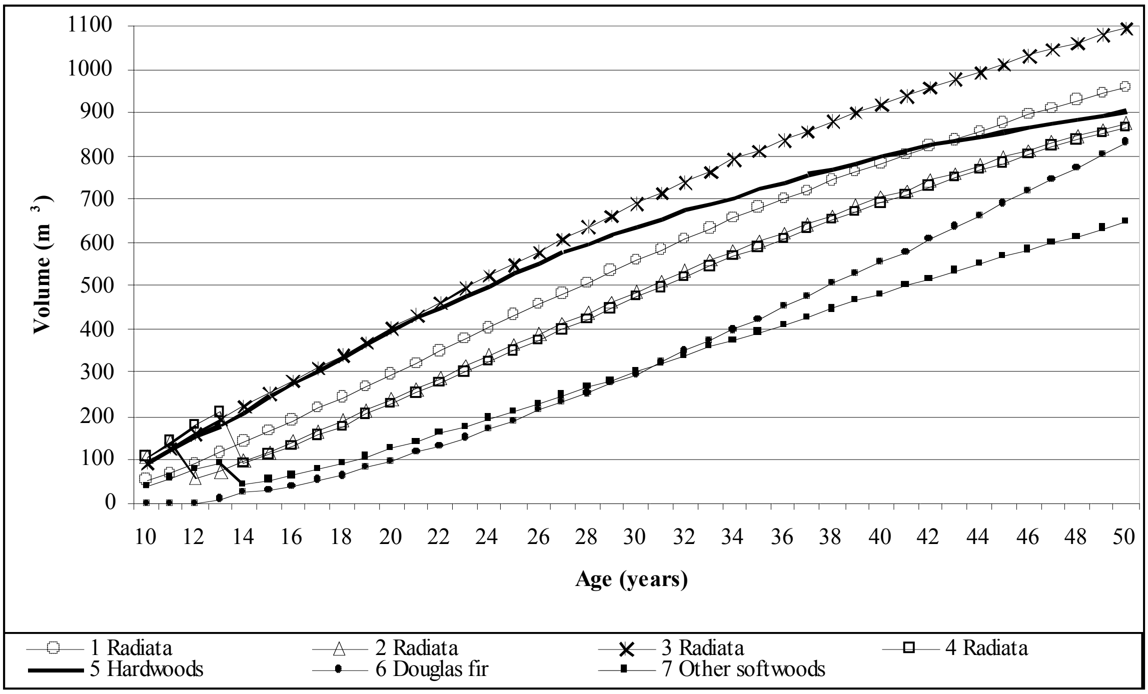

Figure 3. Total Recoverable volume (TRV) in m^3 by age for the selected seven crop types.

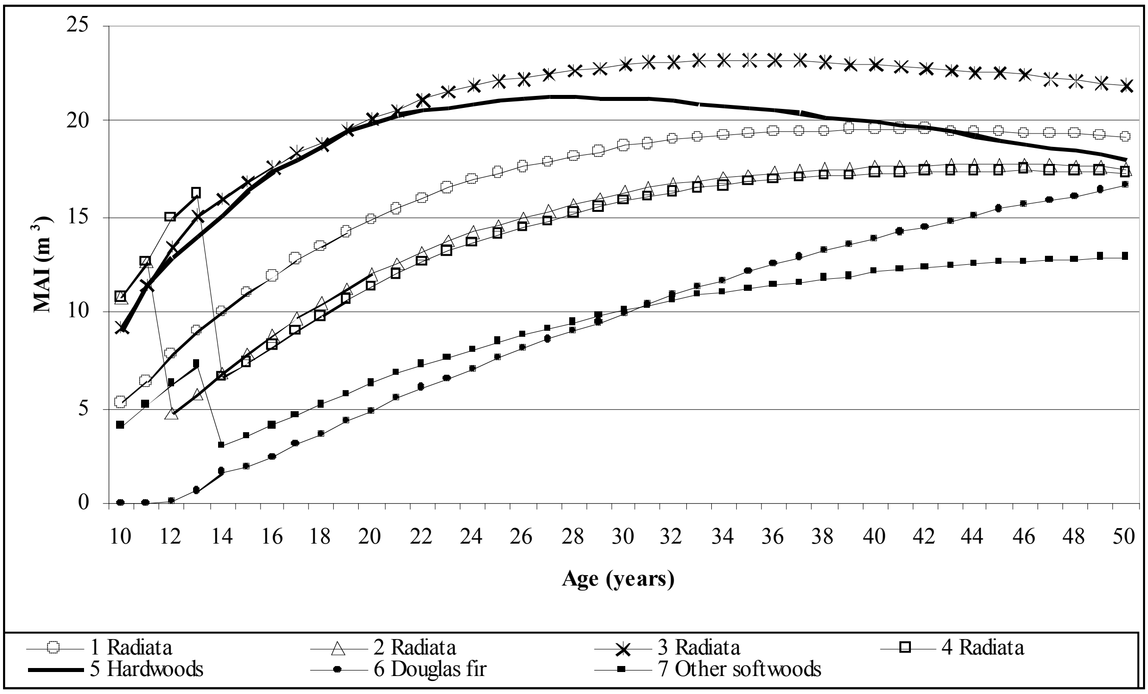

Figure 4. Mean annual increment by age for the selected seven crop types.

Standing trees, harvested logs and carbon estimates at estate level were modelled using the FOLPI estate modelling system (Garcia 1984). To simulate NZ national forest estate, information from NEFD statistics (MAF 2002) on area by age class as at 2001 was used.

The following assumptions were made in calculating the national carbon balance:

- Total carbon harvested is equal to the sum of crown, stem, and floor carbon.
- Crown, and floor carbon will decay on site over time if not removed for bioenergy or other uses.
- Part of stem carbon will be processed and converted into wood products that will decay over time.

This means that carbon harvested does not generate immediate emissions but instead emissions will occur over time depending on the lifetime and decay profile of products and residues. This is an enhancement of the IPCC default assumption (IPCC 1996) under which the annual harvested carbon is emitted instantly. This is consistent with Good Practice Guidance (IPCC 2003) methodologies developed in the which includes instant oxidation of carbon in forest residues as a default but encourages these emissions to be reported more accurately as residues decay over time. No equivalent methodology was proposed for biomass removed from the forest.

Estimates for net atmospheric exchange, total processing, harvested wood products and residue emissions are described in the next sections.

2.3.1 Net Atmospheric Exchange (NAE)

Carbon sequestered by a forest is frequently measured as a stock change. Stock change is derived from the difference between stocks at two points in time. The stock change of a forest integrates all in and out flows of carbon, but does not always reflect the atmospheric exchanges. The NAE is equal to the carbon stock change plus the harvested carbon.

NAE (year t+1) at an estate level (Figure 5) is the result of total standing carbon stock in a given year (year t+1), minus the total standing carbon stock at year t, plus the total carbon harvested in logs (year t+1).

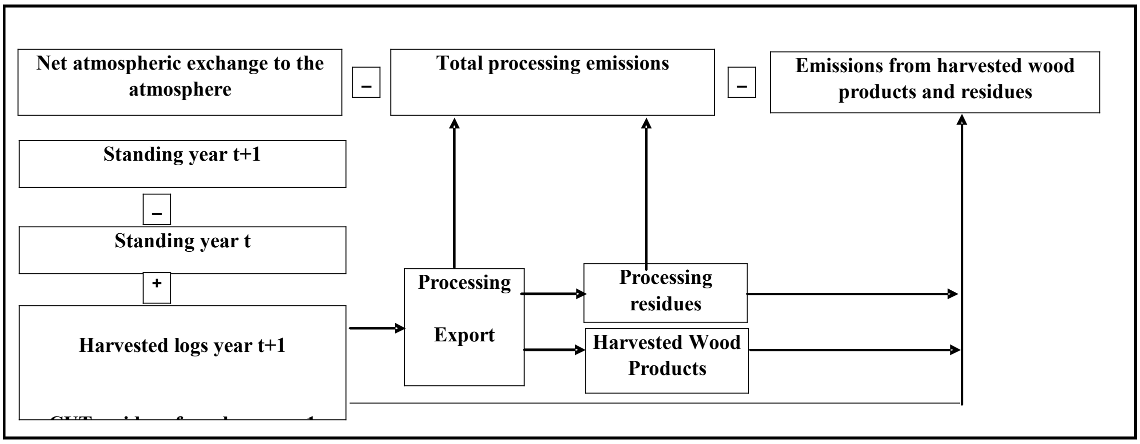

Figure 5. Diagramatic representation of NAE and total emissions.

The NAE of each scenario was estimated relative to the base scenario to assess the impact of changes in land use and forest management on carbon sequestration.

2.3.2 Log Allocation

To estimate the emissions from the forest processing sector, residues and wood products, harvested volumes were allocated to different market destinations, based on the supply of log types and the demand of the processing industry. The total harvested volume was divided into: (i) log types (pruned logs, S1S2, S3L3, L1L2, pulp logs)[4], and (ii) residues from forestry and processing (Figure 6). Merchantable volumes were allocated to different markets: (i) exports, (ii) chemical pulp, (iii) mechanical pulp, (iv) panels (veneer, fibreboard, and particleboard), (v) sawmills. Bioenergy used was included in processing plants and as part of the processing emissions.

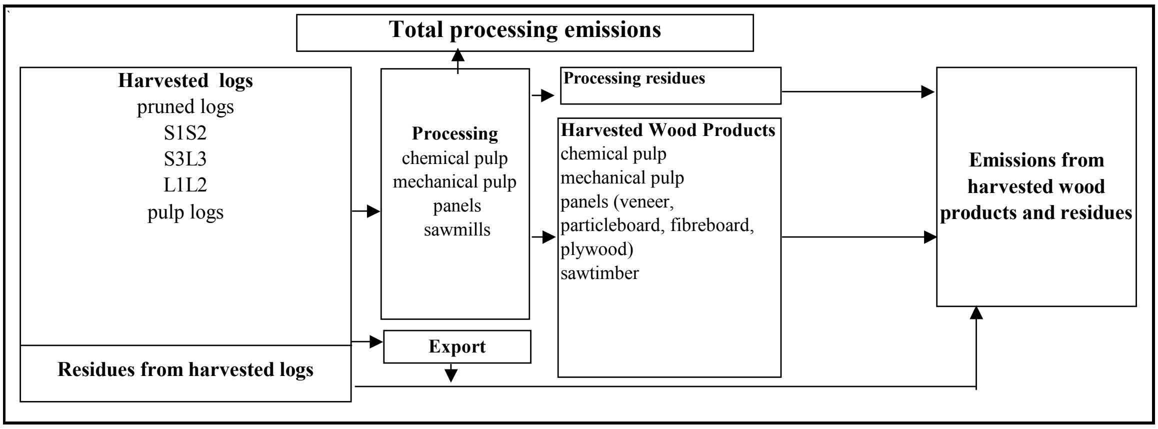

Figure 6. Diagrammatic representation of relationships between log allocation, total processing emissions, wood products and residues emissions.

Log allocation to different processing plants was based on national data on roundwood removals from MAF (MAF 2005b). The base scenario assumed the allocation shown in Table 2. Analysis based on the distribution of logs according to the base scenario forest estate and under the assumptions outlined in the previous sections, yielded a national allocation of total harvested volume to the various destinations in the proportions presented in Table 3. These results were consistent with the national forest statistics at 2001 (MAF 2002).

4 S1S2 are unpruned logs, small end diameter (sed) higher than 300 mm, maximum knot 60 mm; S3L3 are unpruned and pruned logs, sed 200-300 mm and maximum knot 60-140 mm; L1L2 are unpruned logs, sed 200-400 and maximum knot 140 mm.

Table 2. Log allocation of all log types assumed for the base analysis on all scenarios.

Radiata pine	**Export**	**Ch.Pulp**	**Mech.Pulp**	**Sawmill**	**Veneer**	**Particleboard**	**Fibreboard**
Pruned logs	0%			95%	5%		
S1S2	30%			65%	5%		
S3L3	63%	14%	5%	10%		4%	4%
L1L2	65%	14%	5%	10%		3%	3%
Pulp logs	20%	45%	15%			10%	10%
Douglas fir							
Pruned logs	0%			100%			
S1S2				100%			
S3L3				100%			
L1L2				100%			
Pulp logs	50%			50%			
Hardwoods							
Pruned logs	100%			0%			
S1S2		50%	40%		10%		
S3L3		50%	40%		10%		
L1L2		50%	40%		10%		
Pulp logs		60%	40%				
Other softwoods							
Pruned logs							
S1S2	20%			80%			
S3L3	20%			80%			
L1L2	20%			80%			
Pulp logs	50%			50%			

Table 3. Allocation of total harvested volume by market destination

Export	**Ch.Pulp**	**Mech.Pulp**	**Sawmill**	**Veneer**	**Plywood**	**Particleboard**	**Fibreboard**
37,4%	10,2%	4,0%	41,9%	2,3%	0,0%	2,1%	2,1%

Additional volume was set based on current harvested volume. When the level of harvested volume reached a level higher than 19 million m^3, which is the current harvested volume in New Zealand, all volume above that level was set to “additional”. Additional volumes can either be allocated in the same way as in the current (baseline) level or differently. This enables more flexible scenario comparisons to be performed.

2.3.3 Production

An estimate of the production of the processing sector is needed to estimate (i) processing emissions, (ii) emissions from harvested wood product and (iii) residues emissions. It was calculated in tonnes or m^3 of forest products from each processing category, and exports.

Estimates of products produced each year (from 2001 to 2090) were divided into: exports (m^3), chemical pulp (tonnes), mechanical pulp (tonnes), panels such as veneer, particleboard, fibreboard, plywood (tonnes), sawntimber (m^3), and sawmill residues (m^3).

Production was calculated considering (i) total harvested volume, (ii) log allocation for the current level of harvesting, (iii) allocation of ‘additional’ wood harvested in the future and (iv) conversion factors (Table 4) for each processing category.

The following equation provides an estimate for the amount of wood product produced in each category at national level:

$$P_i = \frac{V_{curr} LA_{curr,i} + V_{add} LA_{add,i}}{CF_i} \qquad \text{[Eq] 1}$$

where, P_i is the amount of wood product produced in category i (in either m^3 or tonnes), V_{curr} is the current volume harvested (m^3), V_{add} is the additional volume harvested over and above 19 million m^3 (m^3), $LA_{\mathrm{curr,i}}$ is the log allocation from current production to category i (%), $LA_{\mathrm{add},i}$ is the log allocation from additional production to category i (%), and CF is the conversion factor for category i (m^3/tonne or m^3/m^3).

Current volume is the volume harvested up to 19 million m3. Additional volume is harvested above the current volume. CF is conversion factor which indicates how much roundwood is required to produce 1 m3 or tonne of product. The units are: m3/tonne of pulp, and it is m3/m3 of panels/sawntimber

Table 4. Conversion factors used in calculating production.

Products	Chemical Pulp	Mechanical pulp	Panels	Sawn timber
Conversion factor	3,5	1,64	1,5	1,84

Source: (MAF 2005b)

Sawmill residues were estimated from the total sawn volume (m^3) minus the volume of produced sawntimber (m^3).

2.3.4 Total Processing Emissions

Four categories of processing plants were distinguished to estimate emissions: chemical pulp, mechanical pulp, panels, and sawmills. This categorization was mainly driven by the availability of data on production, energy intensity and GHG emissions provided by Anderson *et al* (2003).

Energy sources considered in this study are gas, coal, electricity, geothermal, other fossil fuels and biomass (Table 5). Emissions from all energy sources (except for biomass) are given in tC/tonne or tC/m3 of product produced by each processing category. Emissions from biomass are tC/tonne of residues allocated to bioenergy use.

Table 5. Categories of energy use in the forest industry.

	Energy source (%)					
	Electricity	**Gas**	**Coal**	**Other fossil**	**Geo/hydro**	**Biomass**
Chemical pulp	13%	0%	0%	1%	0%	86%
Mechanical pulp	87%	10%	0%	3%	0%	0%
Sawn timber	11%	13%	4%	4%	6%	62%
Panels	19%	14%	0%	2%	0%	58%
Total	28%	14%	2%	3%	8%	46%

Source: (Anderson *et al.* 2003)

Estimates of carbon emissions from the forest processing industry refer to emissions from energy use. Annual emissions for each processing category from 2001 to 2090 were calculated by multiplying the production in each category with an appropriate emission factor. The emission factors were derived by multiplying (i) energy use in GJ/tonne or GJ/m^3 of product times (ii) the proportion of all energy sources other than biomass times (iii) the emissions produced by these energy sources in tC/GJ for a given processing category.

The following data and information were used to estimate these emission factors (Table 6):

- Energy use in GJ/unit (tonne or m^3) of product was calculated based on (Anderson *et al.* 2003).
- The proportion of all energy sources other than biomass was taken from (Anderson *et al.* 2003). This report was based on a forest industry survey done by Forest Research in 2003.
- The emissions of all energy sources other than biomass in tC/GJ for a given processing category were calculated by dividing the total emissions from each processing category times the proportion of energy used utilising the various energy sources. Energy use based on energy sources other than biomass in GJ was calculated by multiplying the total energy used times percentage each energy source combined to total energy used.

Table 6. Energy use and emissions in the forest industry (assuming all thermal electricity)
Source: (Anderson *et al.* 2003)

Category	Chemical pulp (tonnes)	Mechanical pulp (tonnes)	Sawn timber (m3)	Panels (m3)
Production	470.000	675.000	1.525.000	388.000
Total energy (GJ)	16.188.330	6.579.263	2.955.314	1.675.120
Energy (GJ/unit)	34,51	9,81	1,93	4,31
Total emissions (tC)	66.041	248.427	34.392	24.689
Emissions tC/unit	0,14	0,37	0,02	0,06
Emissions (tC/GJ)	0,0041	0,0377	0,0104	0,0139
Energy 'other' sources (%)	14%	100%	38%	35%
Energy 'others' (GJ)	2.266.366	6.579.263	1.123.019	586.292
Emissions (tC/GJ of other sources)	0,029	0,038	0,031	0,042

Processing residues not used for bioenergy or other uses are a source of GHG emitted to the atmosphere. These residues do not decay immediately, but over time. Therefore, decay rates were applied. Forest and processing residues as well as harvested wood products are separately accounted for, and the methodologies for these estimations are described in sections 2.3.5, 2.3.6 and 2.3.7.

2.3.5 Forest Residue Emissions

To estimate the emissions from forest residues on site and the emissions that can be avoided by using residues for other purposes such as bioenergy, total carbon and the volume of available residues need to be estimated. Once the total carbon contained in residues is known, the decay rate is applied and emissions per year can be estimated.

Forest residues mainly consist of logging waste and tree crowns. Available residues (tC) were calculated as the sum of these two components. Crown carbon was estimated from the C_change and FOLPI models, while the amount of carbon contained in logging waste (LW) was estimated from the following equation:

$$LW = TC\left(1 - \frac{TRV}{TSV}\right) \qquad \text{[Eq] 2}$$

where TC is the total carbon stored in forest vegetation (tC), TRV is the total recoverable volume (m^3), and TSV is the total standing volume (m^3).

The oven-dry mass of residues (tonnes) was calculated by dividing the available residues (tC) by 0.5; this corresponds to the average carbon content recommended by IPCC (2003 – Appendix 3a1)."

Emissions from forest residues arise when these residues decay on site. However, when removed from site (i.e. used for different purposes such as bioenergy) the total carbon contained in these residues is assumed to be immediately released to the atmosphere. With this approach no emissions are allocated to energy generated from biomass but to the residues used. The same approach was applied to processing residues.

The forest residues present on site in a particular year consist of the residues generated and left on site in the current year plus the residues left from previous years. Residues decay over time and emit carbon to the atmosphere. To estimate these emissions, a decay rate of 18% per year was applied, based on Beets *et al.* (1999).

2.3.6 Harvested Wood Products Emissions

In order to represent the products emissions, the lifetime of products and the decay profile need to be determined. Lifetimes can be estimated for product categories, as in the Dakar approaches (Brown *et al* 1999). Schlamadinger *et al*. (1996) and Maclaren and Wakelin (1991) classify products into 3 classes, and estimate the proportion of each product. Estimates for total domestic harvested volume in New Zealand (Maclaren and Wakelin 1991) indicate that: 2% of harvested logs end up in products with an estimated life (linear decay) of 80 years, 20% in products lasting 50 years and 78% in short life products lasting only 1 year before being emitted. The decay profile is related to the lifetime of the product.

The approach to estimate product emissions considered in this study used the data above to determine the lifetime for each product category. A linear decay over the products lifetime was assumed, and hence, nothing was left at the end of that period. The decay rate and carbon content assumed for wood products was: (i) 78% linear decay for pulp, (ii) 10% linear decay for panels and (iii) 1.6% linear decay for sawntimber. Products exported were not differentiated from the domestic products, and hence emissions were allocated to the producer using the same decay profile.

When logs are exported and product use is unknown, a conservative approach is followed, thus instantaneous emissions of all export logs is assumed.

The IPCC default value of 0.5 tonne C/oven-dry tonne (odt) was used to convert tonnes of products into tonnes of carbon (IPCC 1996).

This study assumes a similar decay over time for the products as it does for the residues left in the forest and suggests the emissions remain the responsibility of the producer. This is consistent with the default assumption of instant oxidation reported by the producer, but this allocation could be the subject of future negotiations.

2.3.7 Processing Residue Emissions

The processing residues present on site in a particular year consist of the residues generated and left on site in this year plus the residues left from previous years. Residues decay over time and emit carbon to the atmosphere. To estimate these emissions, a linear decay rate of 20% per year was applied to the available residues.

To estimate processing residue emissions the available volume of residues and total carbon needs to be estimated. Processing residues were assumed to be the wood from sawmills that is not converted into products (i.e logs allocated to sawmills minus sawn timber produced).

The general default value of 0.5 tonnes C/tonne oven dry biomass recommended by the IPCC (1996) was used to convert tonnes of processing residues into tonnes of carbon contained in residues.

2.3.8 Residues used for Bioenergy

Forest and processing residues are potentially a source of energy from biomass. Harvesting methods, forest/tree form in different regions, and the level of silvicultural management determine the distribution, quantity and nature of the residues. Only a proportion of the total residue resource is available for potential power production due to economic, technical and environmental reasons.

In this study it was assumed that 50% of forest residues could be removed for bioenergy use, from which 100% was available for bioenergy and only 10% of processing residues was available and used for bioenergy given that the surplus appears to be used by other markets (Anderson *et al.* 2003).

2.4 Scenario Analysis

Seven national forest estate scenarios were simulated to model the New Zealand forest estate based on current and possible future circumstances:

1. Base scenario: This scenario was derived using the current New Zealand forest estate (NEFD) with the aim to represent the current conditions.
2. Deforestation scenario: This scenario was developed to analyse the implications of potential deforestation.
3. Target rotation: This scenario represents a possible change in management practices in which rotation length is extended.
4. Limit on harvesting: In this scenario a cap is put on harvested volume leading to an extension of rotation length.
5. New land planting scenarios: In these three scenarios (i) 20 thousand hectares of the same croptypes as in the base scenario, (ii) 60 thousand hectares of the same croptypes as in the base scenario and (iii) 60 thousand hectares of hardwoods are planted on new land each year.

All model simulations were started with the New Zealand forest estate net stocked area by age class as at 2001, representing the entire planted production forest. The total net stocked forest area that formed the base data for these models was 1.9 million hectares. The area by species (hectares) at 2001 was: (i) 1.7 million of radiata pine; (ii) 102,000 for Douglas-fir; (iii) 33,000 for other softwoods; and (iv) 50,000 for hardwoods.

1)Base scenario. The base scenario was designed to show a scenario with non declining yield constraints, replanting with the same croptypes, no new planting, and clearfell ages.

- Clearfell yields were constrained to be non-declining (ie, the total clearfelled volume in any one year was required to be greater than or equal to the yield in the previous year).
- Minimum clearfell age for radiata pine was set to 27 years.
- Minimum clearfell age for Douglas fir was set to 40 years
- Minimum clearfell age for hardwoods was set to 10 years
- Eucalyptus age was assumed short-rotation crop
- Area clearfelled in each crop type was replanted into the same croptype.

Scenarios 2 to 7 are variations of scenario 1 (base) but evaluate alternative replanting, harvesting, target rotation and new planting strategies.

2) Deforestation. There was no replanting after clearfelling or any afforestation. It was conservatively assumed that all harvested area was converted into bareland (i.e. no emissions from new land use such as pasture or cropping).

3) Limit on harvesting. The harvesting volume was limited to the 2001 level

4) Target rotation. Target clearfell age models changed the minimum and maximum clearfell age for radiata pine. Minimum clearfell age for radiata pine was set to 32 and 34 (from 27 years). Maximum clearfell age was set to 50 years (instead of 45 and 35 years). The rotation ages for the species other than radiata pine remained the same in each scenario.

NEW PLANTING SCENARIOS

Three levels of national new planting scenarios were modelled. These levels of new planting were held constant over the period 1 to 50, starting at 2001.

5) New planting of 20 thousand hectares per year from year 1 to 50. New planting was allocated to crop types in proportion to the existing area of each crop type.

6) New planting of 60 thousand hectares per year from year 1 to 50. New planting was allocated to crop types in proportion to the existing area of each crop type.

7) New planting of 60 thousand hectares of hardwoods per year from year 1 to 50. New planting of bareland was allocated to the hardwood croptype only.

The scenarios modelled in this study assumed that planted forests in New Zealand are managed to be cut towards the minimum clearfell age specified.

For each scenario the net atmospheric exchange (NAE), net present value (NPV) of forest plantations, and the carbon balance for the whole industry was estimated. Afterwards, each scenario's NAE, NPV and balance relative to the base scenario were calculated. To identify the effects of discounting on NAE and balance and to enable comparison between scenarios, the present value of NAE and the present value of balance were estimated. The impacts of the different land use scenarios were examined. Finally, the breakeven carbon unit value assuming different land values was assessed for the new planting and deforestation scenarios. NAE and carbon balance estimations over time were described in the previous sections. In the following section, NPV, NAE and balance present value as well as carbon unit value are explained.

2.4.1 NPV for all Scenarios

The NPV of forest plantation cash flows was calculated by summing up the present value of expected revenues of the scenario minus the sum of the present value of costs. Land value was not included in the cash flow analysis (i.e for deforestation revenues the value of land is not included, for new planting the cost of new land is not included). Land revenues and costs are considered in the subsequent analysis of carbon values. The NPV is expressed by the following formula:

$$NPV = \sum_{y=0}^{n} \frac{R_y}{(1+i)^y} - \sum_{y=0}^{n} \frac{C_y}{(1+i)^y} \qquad \text{[Eq] 3}$$

where R_y and C_y are revenues and costs at age y, respectively, and i is the discount rate.

The discount rate used for these estimations was 8% based on a survey developed by Manley (1999). Silvicultural costs and log prices assumed in the study are shown in Table 7 and Table 8. Transport costs were assumed to be \$15 / m^3 and harvesting costs \$20 /m^3. Relative NPV (i.e difference between each scenarios and the base scenario) was estimated.

Table 7. Silvicultural costs for all regimes and age when they occurred.

		Silvicultural costs NZ$			
Croptype	**Age**	**Land preparation+ initial weed control**	**Tree releasing**	**Pruning**	**Thinning**
1	1	1100	240		
	2				
	6			700	400
	8			650	
	9			600	350
2	1	1100			
	2		240		
	6			700	400
	8			650	
	9			600	
	12				
3	1	1100			
	2				
	6				
4	1	1100			
	2		310		
	6				
	14				
5	1	1700			
6	1	1700			
	15				500
7	1	1700			
	10				500

Table 8. Log prices ($/m^3) for species log grades. Source:(MAF 2005a)

	Prices NZ$/m3			
Log type	**Radiata**	**D. fir**	**Hardwoods**	**Other softwoods**
PR	147	160		
S1S2	86	102		129
S3L3	63	102		
L1L2	66	102	85	
PULP	40	35	40	35

2.4.2 Present Value of NAE and Present Value of Balance (tC/yr)

In order to compare different scenarios, the present value of NAE and carbon balance was estimated. The discount rate used was the same as for the economic analysis. The following formula was used to estimate the present value of NAE:

$$\text{Present value of NAE} = \sum_{y=0}^{n} \frac{NAE_y}{(1+i)^y} \qquad \text{[Eq] 4}$$

The next formula was used to estimate the present value of carbon balance.

Present value of Balance = $\sum_{y=0}^{n} \frac{Balance_y}{(1+i)^y}$ [Eq] 5

Where y is years from now and *i* discount rate.

Each scenario NAE and balance relative to base were also estimated applying the following formula:

Relative NAE sc_n to sc_b = Present value of NAE sc_n – Present value of NAE sc_b[Eq] 6

where sc means scenario and n the given scenario that is compared to base

2.4.3 Carbon Unit Value ($/tC)

If 'deforestation' scenario (2) is shown to be the best economic option (i.e NPV) than the base scenario:

$NPVdeforestation \geq NPVbase$

However, deforestation would not be beneficial for the environment, since it showed lower NAE:

$NAEdeforestation \leq NAEbase$

and hence, negative NAE relative to the base scenario.

In order to make the base scenario worthwhile instead of deforesting the land, the economic benefits have to equal the environmental benefits (i.e Economic benefits = Environmental benefits). Therefore, additional revenues, such as from carbon are needed.

The monetary value, and hence, the additional revenues needed, of the difference between both scenarios's NAE is given by relative NAE times carbon value (i.e Relative NAE (tC)* Carbon value ($/tC).

The additional revenues when land use management changed from the base scenario to deforestation (2) are given by the relative NPV to base scenario plus land revenues earned from the land that is being sold (i.e Relative NPV + land value) .

The value of carbon ($/tC) which makes the base scenario worthwhile was estimated, assuming a range of land values. The following formula was applied for the deforestation (2) scenarios

*Relative NPV + Land revenues =-Relative NAE (tC) * Carbon value ($/tC)* [Eq] 7

where relative NPV is the given scenario NPV relative to base; land revenues and the present value of the land that could have been sold after deforestation; and relative NAE is the given scenario NAE relative to base.

Furthermore, the NPV of new land planting scenarios was lower than the base scenario, therefore, the preferred economic option would be to remain in the base scenario. All these scenarios showed higher NAE and hence, a change in land use management would be desirable for mitigation purposes. In order to have an incentive to change from the base scenario, additional revenues from carbon are needed. The same condition apply, so that, for a known NPV (negative relative NPV to base scenario) plus land costs of new land planting, additional carbon value is needed to make the decision to plant new land indifferent or worthwhile.

The following formula was applied for the new planting scenario:

*-Relative NPV($)+Land cost ($)=Relative NAE (tC) * Carbon value ($/tC)* [Eq] 8

Where land cost is the present value of land that was bought for new planting

Carbon value in $ per tonne of carbon was estimated for the regimes where deforestation and new land planting occurred (scenarios 2, 5, 6, and 7).

The area harvested and planted (i.e. costs and revenues from land) was discounted using the same discount rate for NAE as for the discounted cash flow analysis (i.e. 8%). Land costs and revenues were set from 0 to $12000/ha and the value of carbon was estimated for each land value.

The same approach was applied to estimate the carbon unit value based on the carbon balance for the whole industry. The following formula was applied for the deforestation scenario

*Relative NPV + Land revenues =-Relative Balance (tC) * Carbon unit price ($/C)* Eq] 9

and, the next formula was applied for the new planting scenarios

*-Relative NPV($+-Land cost ($)= Relative Balance(tC)*Carbon unit price($/tC)* [Eq] 10

2.5 Results and Discussion

The attained estimates for total recoverable volume (m^3), net atmospheric exchange (tC/yr), carbon balance (tC/yr), net present value ($) and carbon unit value ($/tC) are presented in the following sections, and the analysis for each indicator is discussed.

2.5.1 Total Recoverable Volume (m^3)

The total recoverable volume (TRV) in m^3 calculated for the seven scenarios modelled is shown in Figure 7. In the base scenario the TRV increased to approximately 36 million m^3 during the first ten years, and remained at this level in the long term. In all new planting scenarios (5, 6, and 7) the TRV increased above the level of the base scenario. The TRV in the 'limit on harvesting' scenario (3) remained constant over time, and at the same level as in the beginning of the period due to the constraint set on harvesting. The TRV in the 'deforestation' scenario (2) decreased over time, because the area harvested was converted to bare land. The volume in the longer rotation age scenario (4) increased over time, attaining slightly higher levels than achieved in the base scenario.

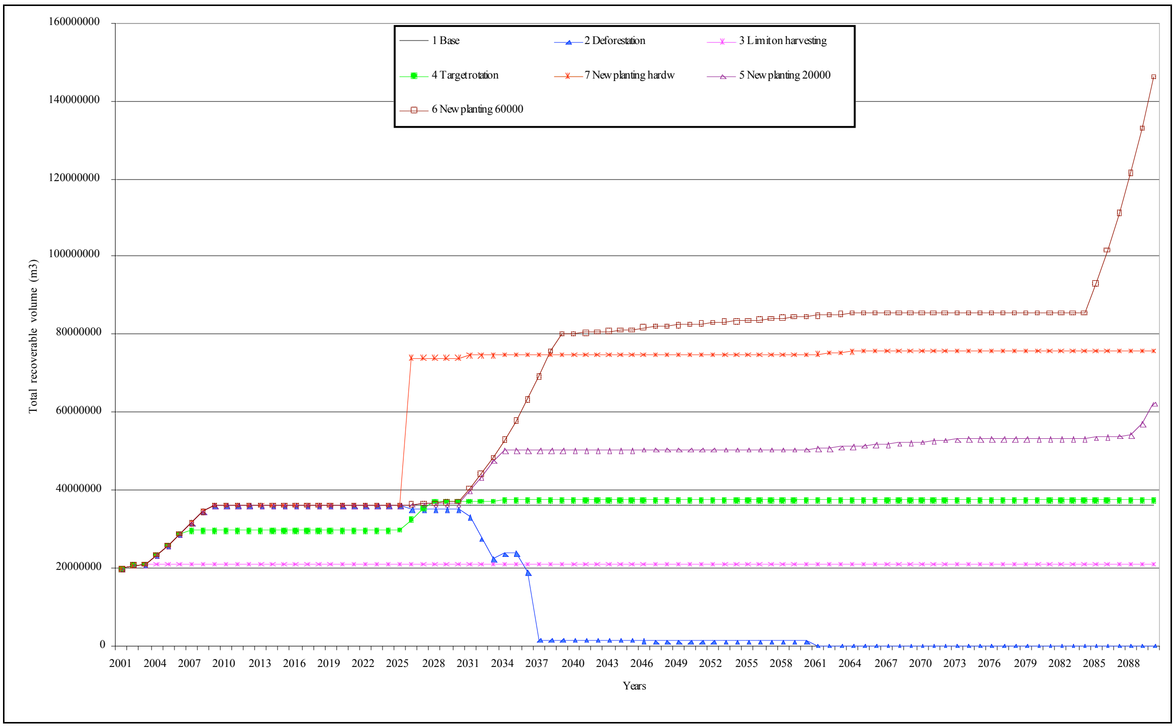

Figure 7. Total recoverable volume (TRV) in m^3 over time for scenarios 1-7.

2.5.2 Net Atmospheric Exchange (tC/year)

The simulated net atmospheric exchange (NAE, in tC/year) for the seven scenarios is illustrated in Figure 8. The base scenario showed a stable level of NAE over time, at approximately 16 million tC/yr.

In all new planting scenarios (5, 6, and 7) the NAE increased and stabilised in the long term at a higher level than in the base scenario. NAE in the scenario with ‘limit on harvesting’ (4) declined over time to a lower level than in the base scenario. This was the result of the constant amount of carbon being harvested in this scenario resulting in a decreasing rate of carbon stock change. The increment in carbon stock did not compensate for the carbon harvested over time, and hence, the net uptake of carbon from the atmosphere decreased.

In the deforestation scenario (2) the NAE diminished over time. The scenario with longer rotation age showed a similar trend than the base scenario, but overall slightly higher values.

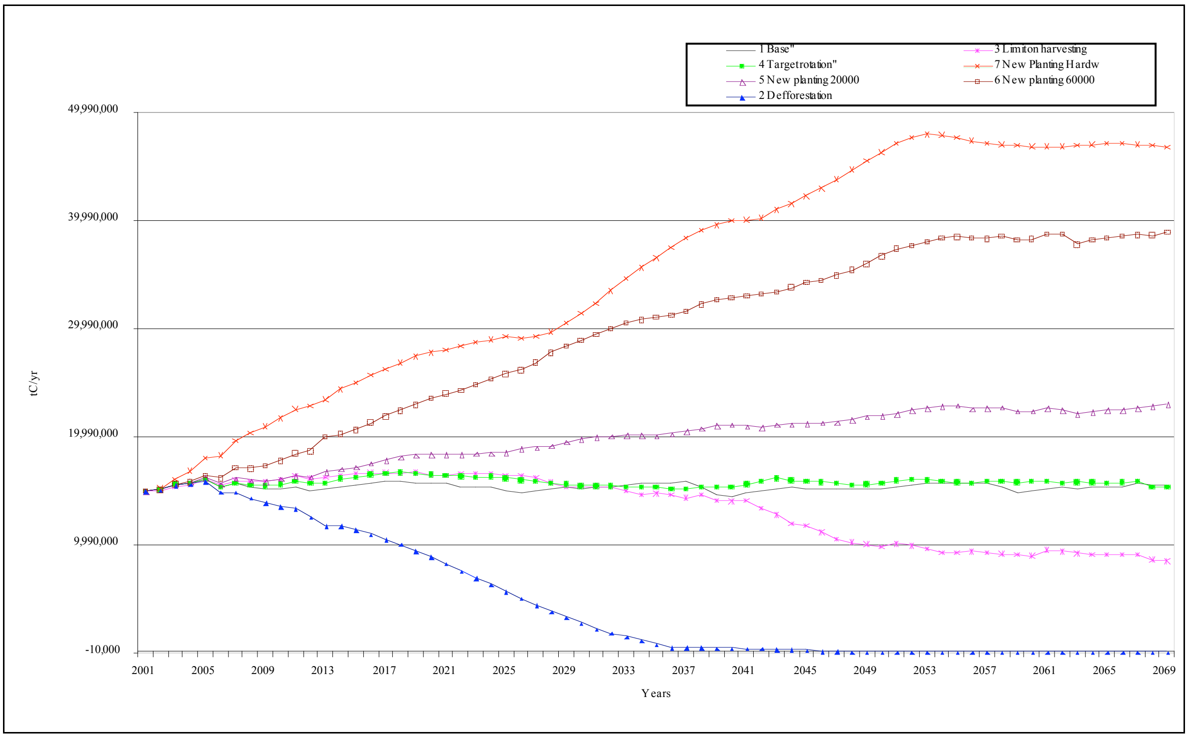

Figure 8. NAE (tC/year) over time for scenarios 1-7.

The undiscounted NAE and present values of the NAE (i.e discounted at 8%) for the seven scenarios are illustrated in Figure 9. The present value accounts for the effect of discounting of carbon benefits. This allowed comparison to the net present value (NPV) ($) achieved under each scenario.

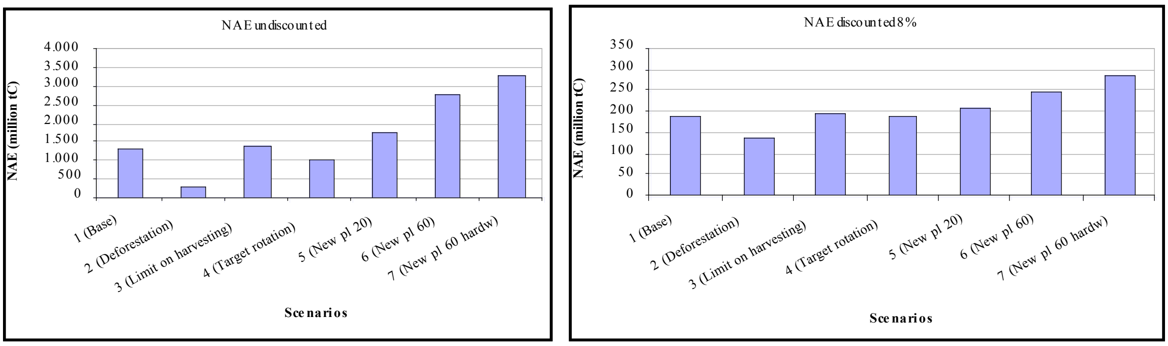

Figure 9. Sum of NAE and present value of NAE (at 8% discount rate) for all scenarios.

The three new planting scenarios (5-7) showed the highest present values of NAE (Table 9), followed by the ‘limit on harvesting’ (3), ‘target rotation’ (4), ‘base’ (1), and ‘deforestation’ scenario (2), in order of decreasing present NAE.

Table 9. Present value of NAE (millions tC) for all scenarios.

Scenario	NAE (million tC)	NAE relative to base
1 (Base)	191	
2 (Deforestation)	144	-47
3 (Limit on harvesting)	194	2
4 (Target rotation)	195	4
5 (New pl 20)	211	19
6 (New pl 60)	250	58
7 (New pl 60 hardw)	286	95

Although discounting reduces the value of the long term carbon uptake from the atmosphere, at the 8% discount rate used in the model, the ranking of scenarios remained almost constant. The 'limit on harvesting' scenario (3) showed similar values as 'target rotation' (4); this implies that both have similar impacts on the atmosphere. When NAE was modelled over time (Figure 8) the long term benefits of 'limit on harvesting' (3) decreased below the level of the base scenario, while those of the 'target rotation' scenario (4) remained almost constant and above the base scenario. Discounting masked the long term negative impact of the 'limit on harvesting' scenario.

The analysis demonstrated that net values and present values could lead to different conclusions with regard to mitigation options. Consequently, caution should be taken when making decisions about mitigation options based on discounted or undiscounted values, respectively. Whether and when it is appropriate to use discounted values, and which discount rates should be used to account for carbon benefits, will be discussed in Chapter 5 of this report.

2.5.3 Carbon Balance (tC/year)

The carbon balances for the seven scenarios are illustrated in Figure 10. Figure 12 shows the balance for the three 'new planting' scenarios (5, 6 and 7) and the base scenario, and Figure 13 illustrates the 'limit on harvesting' (3), 'target rotation' (4), 'deforestation' (2) and base scenarios. Given that the carbon balance is the result of NAE minus total emissions, Figure 11 presents the estimates of emissions over time. Figure 15 shows the trends for NAE, total emissions and resulting carbon balance over time, separately for each scenario.

In the base scenario, the annual carbon balance is almost constant, after a decline during the first ten years (Figure 10).

In the two scenarios assuming new planting with the same crop types (5 and 6), the high NAE increment (Figure 8) compensates for the emissions released by the processing of wood from new planting areas (Figure 11). Thus, the carbon balance stabilises over time at a higher level than in the base scenario (Figure 12). The scenario assuming new planting of sixty thousand hectares of softwoods (6) was the only scenario that showed an increase in the carbon balance over time.

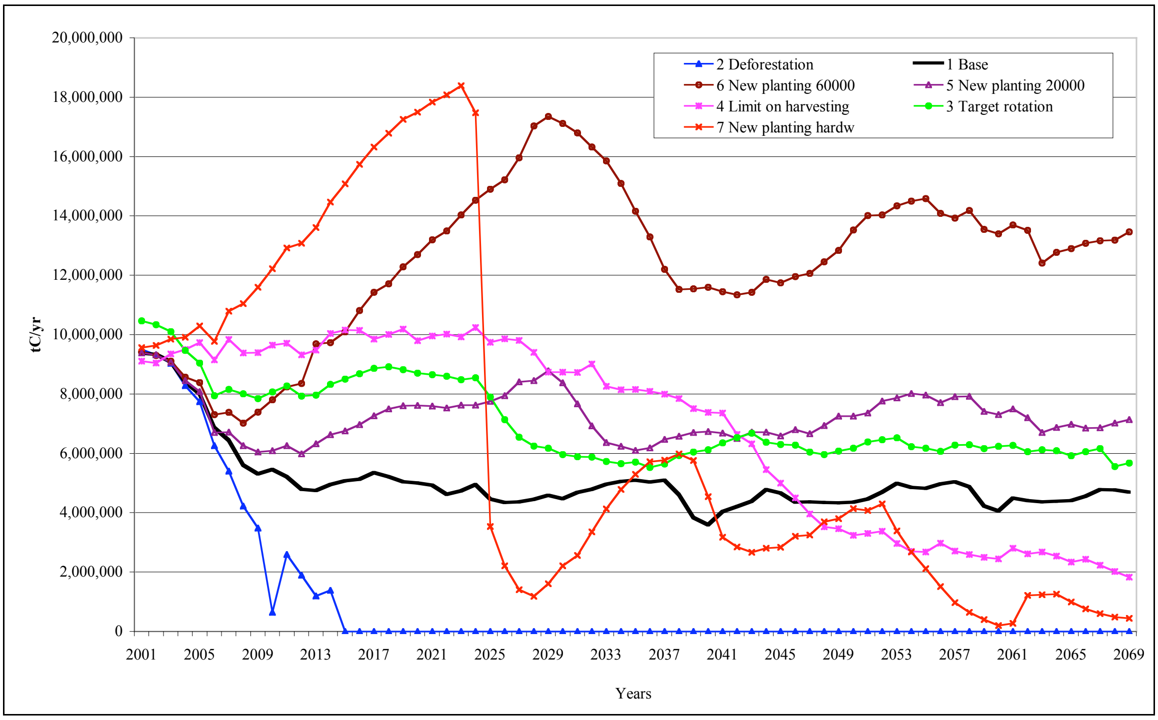

Figure 10. Estimated carbon balance (tC/yr) over time for scenarios 1-7.

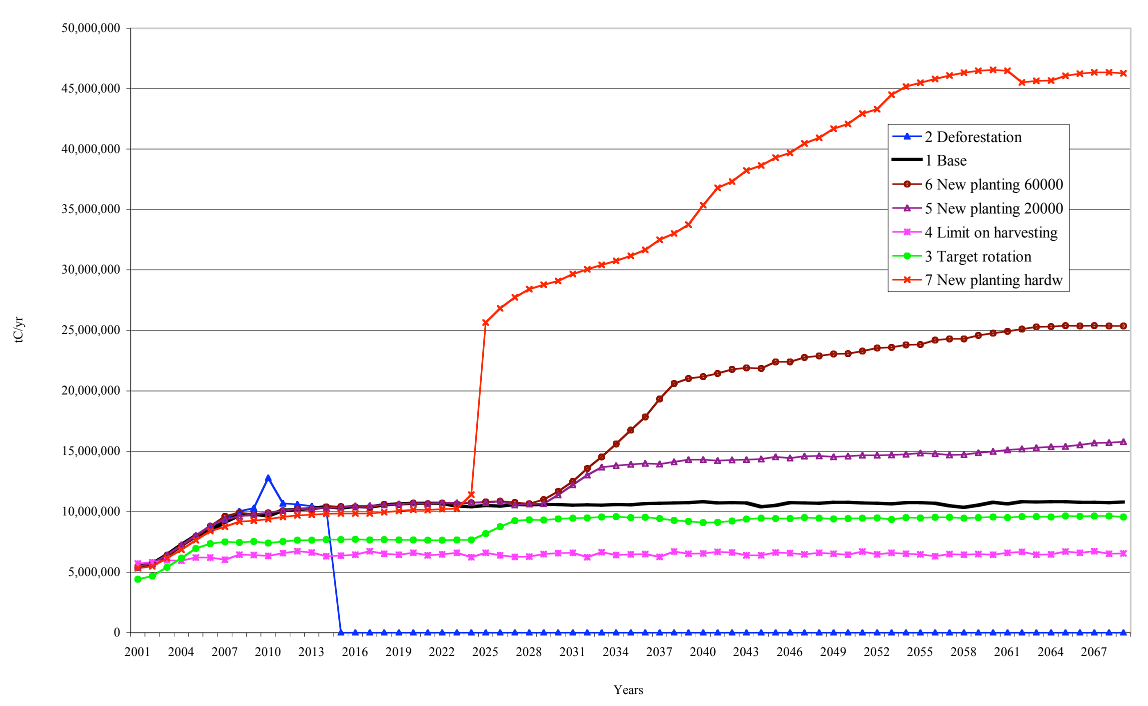

Figure 11. Estimated total emissions (tC/yr) over time for scenarios 1-7 .

The new planting scenario assuming planting 60 thousand hectares of hardwoods showed an increased carbon balance in the short term until the emissions reached a peak (Figure 11). This caused the carbon balance to decrease to a level below that of the base scenario (Figure 15). The increase in total emissions corresponds mainly to emissions from harvesting and processing the additional total recoverable volume from the new planting area, as well as to emissions produced by associated forest residues.

Figure 12. Balance (tC/yr) for base and all new planting scenarios

In the short term, the ‘target rotation’ (4) and ‘limit on harvesting’ (3) scenarios showed higher carbon balances than the base scenario. The carbon balance in the ‘target rotation’ scenario remained above the level in the base scenario over time, but decreased in the ‘limit on harvesting’ scenario over the period to a lower level than in the base scenario. In the ‘limit on harvesting’ scenario the NAE decreased over time, while emissions remained stable due to the constant TRV being processed. Consequently, the carbon balance followed the trend of the NAE over the whole period modelled. The decreasing balance in the ‘target rotation’ scenario was the result of a stable NAE minus increasing emissions over time.

The ‘deforestation’ scenario (2) showed the lowest carbon balance attaining negative values in the long term. This was caused by the decreasing NAE and incremental emissions typical for this scenario.

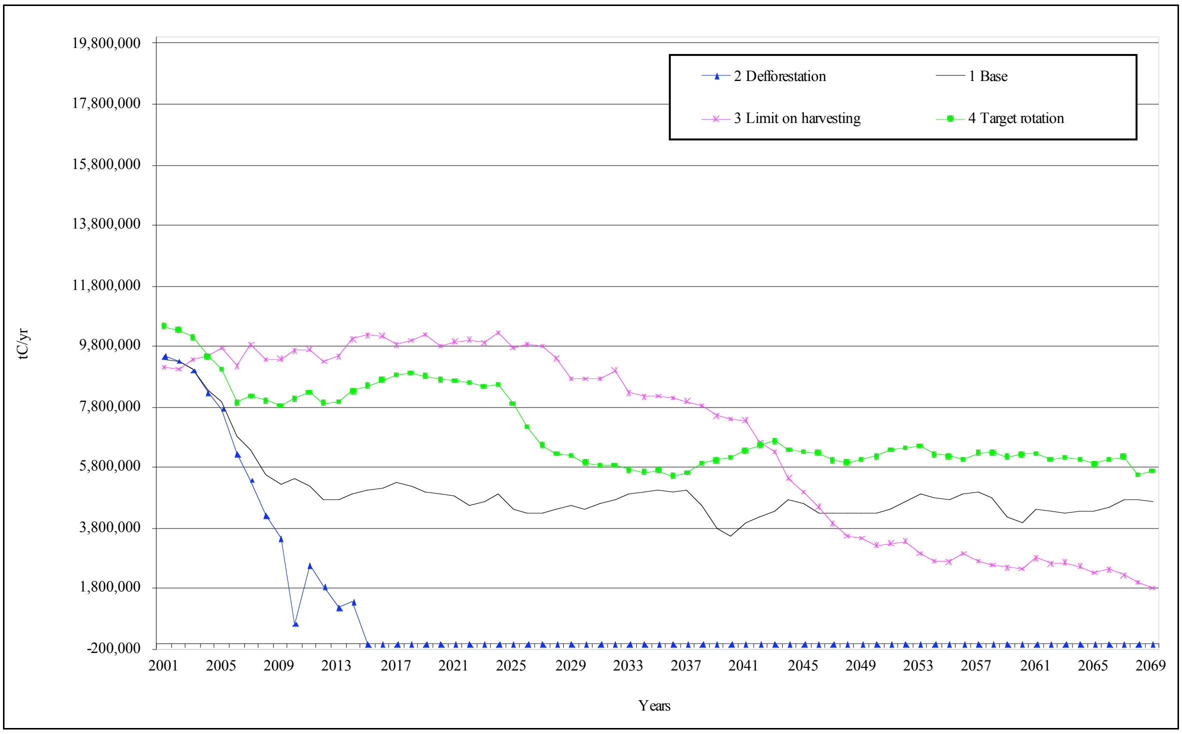

Figure 13. Balance (tC/yr) for 'base', 'limit on harvesting'(3), 'target rotation' (4) and 'deforestation' (2) scenarios

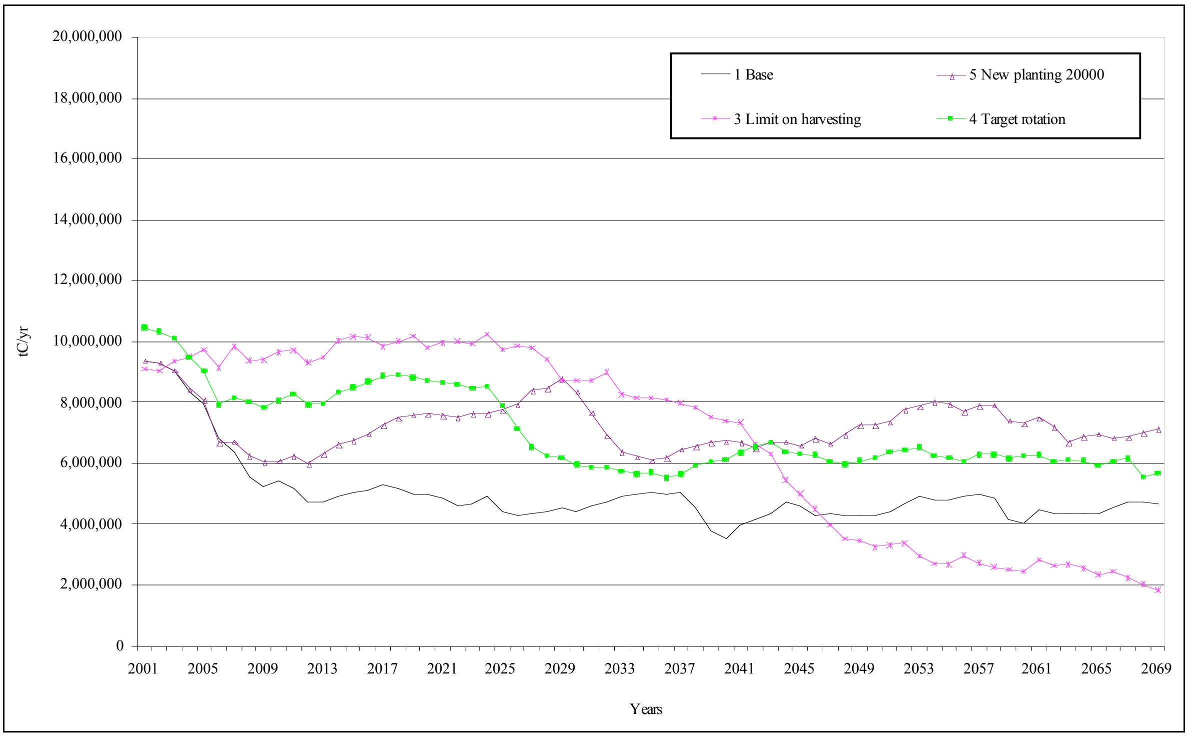

Figure 14. Balance (tC/yr) for 'base', 'limit on harvesting'(3), 'target rotation' (4) and 'new planting 20 thousand hectares' scenario.

In Figure 14 can be seen that there was an interaction between scenarios over time. In the short term, the 'new planting 20 thousand hectares' scenario showed a lower carbon balance than the 'target rotation' (4) and 'limit on harvesting' (3) scenarios, but it attained higher levels than these scenarios in the long term.

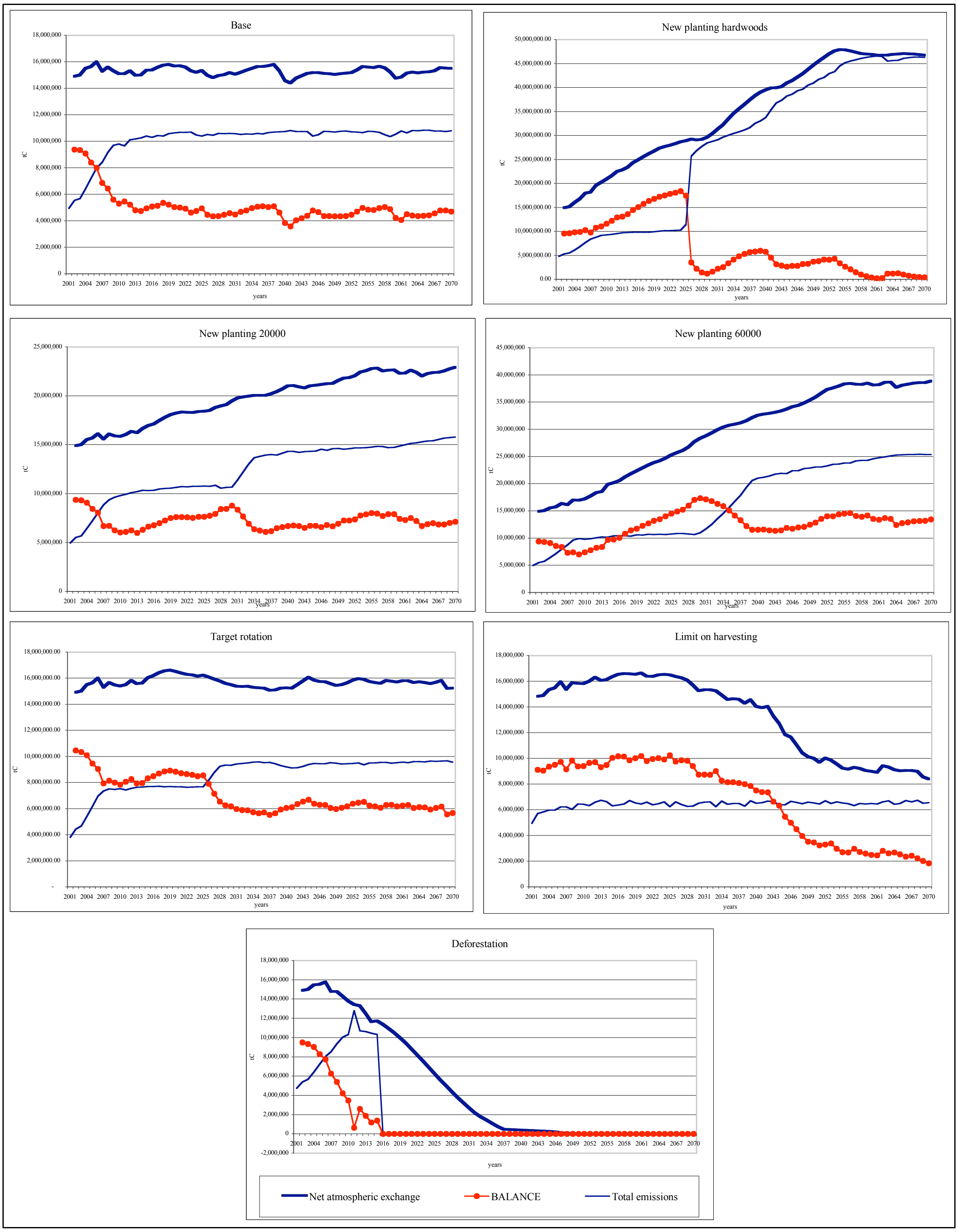

Figure 15. Carbon balance, NAE and emissions (tC/yr) for each scenario separately.

All scenarios were also analysed for the present value of carbon balance achieved, and the results are presented in Table 10 and Figure 16. The two new planting scenarios assuming 60 thousand hectares of new planting with the same croptype as previously and hardwoods, respectively, showed the highest present values of carbon balance, followed by the 'limit on harvesting', 'target rotation', '20 thousand hectares of new planting', 'base' and 'deforestation' scenarios, in order of decreasing present value.

The 'deforestation' scenario showed a negative carbon balance in the long term, but the present value remained positive. Thus, the long term negative effect can be concealed by discounting and would also be concealed without discounting.

Even though the carbon balance in the 'limit on harvesting' scenario decreased, and the balance in the 'target rotation' scenario was higher than in the base scenario over time, the present values in both two scenarios showed similar levels. These results lead to the conclusion that both scenarios are comparable in the short term, while in the long term, the 'limit on harvesting' scenario provides less benefit to the atmosphere than the increasing rotation age scenario.

As a consequence of discounting, the present value carbon balance for the 'new planting 20 thousand hectares' scenario was lower than the 'target rotation' and 'limit on harvesting' scenarios. The lower net values attained in the new planning 20 thousand hectares scenario in the short term were enhanced, leading to an overall lower present value in this scenario.

Table 10. Present value of carbon balance (tC) for all scenarios

Scenario	Present value of balance (million tC)	Balance relative to base
1 (Base)	76	
2 (Deforestation)	39	-37
3 (Limit on harvesting)	115	39
4 (Target rotation)	103	27
5 (New pl 20)	90	14
6 (New pl 60)	121	45
7 (New pl 60 hardw)	130	54

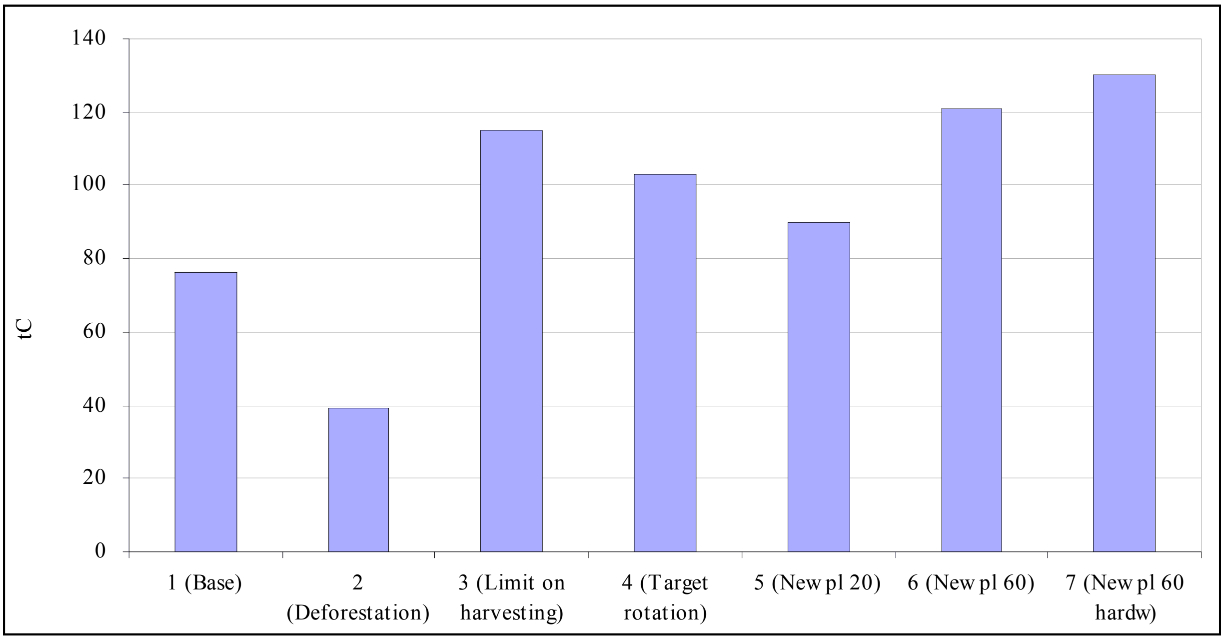

Figure 16. Present value of carbon balance (tC) for all scenarios

2.5.4 NPV for all Scenarios (8% discount rate)

Estimated Net Present Value (NPV) and associated costs and revenues are presented for all scenarios in Table 11 and Figure 17. Scenario 2 (deforestation) showed the highest NPV, followed by scenarios 1 (base), 5 (new planting 20 thousand ha), 6 (new planting 60 thousand ha), 7 (new planting hardwoods), 4 (target rotation) and 3 (limit on harvesting). Under the assumptions made in this study the most profitable scenario was 'deforestation', driven by the low cost profile associated with non-replanting. It was the only scenario that gave higher returns than the base.

Table 11. NPV , costs and revenues million $) for all scenarios.

Scenarios	NPV (Millions NZ$)	Discounted Costs (Millions NZ$)	Discounted Revenues (Millions NZ$)
1 (Base)	15,527	19,768	35,295
2 (Deforestation)	15,609	16,803	32,412
3 (Limit on harvesting)	10,009	13,789	23,799
4 (Target rotation)	14,049	18,047	32,096
5 (New pl 20)	15,467	21,115	36,581
6 (New pl 60)	15,317	23,493	38,809
7 (New pl 60 hardw)	14,294	25,425	39,720

The new planting scenarios showed lower NPV as a result of the costs of the new land planting associated with this management regime. These costs were not compensated by the future increment in revenues. The returns of these scenarios were lower than the 8% discount rate used in the analysis. Scenario 5 (20 thousand hectares of new planting) is associated with lower annual costs than Scenario 6 (60 thousand hectares of new planting), which led to a slightly higher NPV. The cost of planting of hardwoods (Scenario 7) is higher than for other crop types, resulting in a lower NPV for this scenario compared to scenarios 5 and 6. In scenario 3 (Limit on harvesting) revenues decline over time, leading to a markedly lower NPV compared to the other scenarios. Even though the target rotation scenario modelled longer rotation and hence, a higher value of logs at harvesting with a slightly higher TRV, this increment did not offset the loss associated with delayed revenues.

'Deforestation' was the only scenario with a positive NPV relative to the base scenario. This means it would be profitable to change land use management, but the NAE relative to base was negative, i.e this scenario resulted in a negative effect on the atmosphere. While all other scenarios showed negative NPV compared to the base scenario, their relative NAE levels were positive, making these scenarios beneficial to the atmosphere.

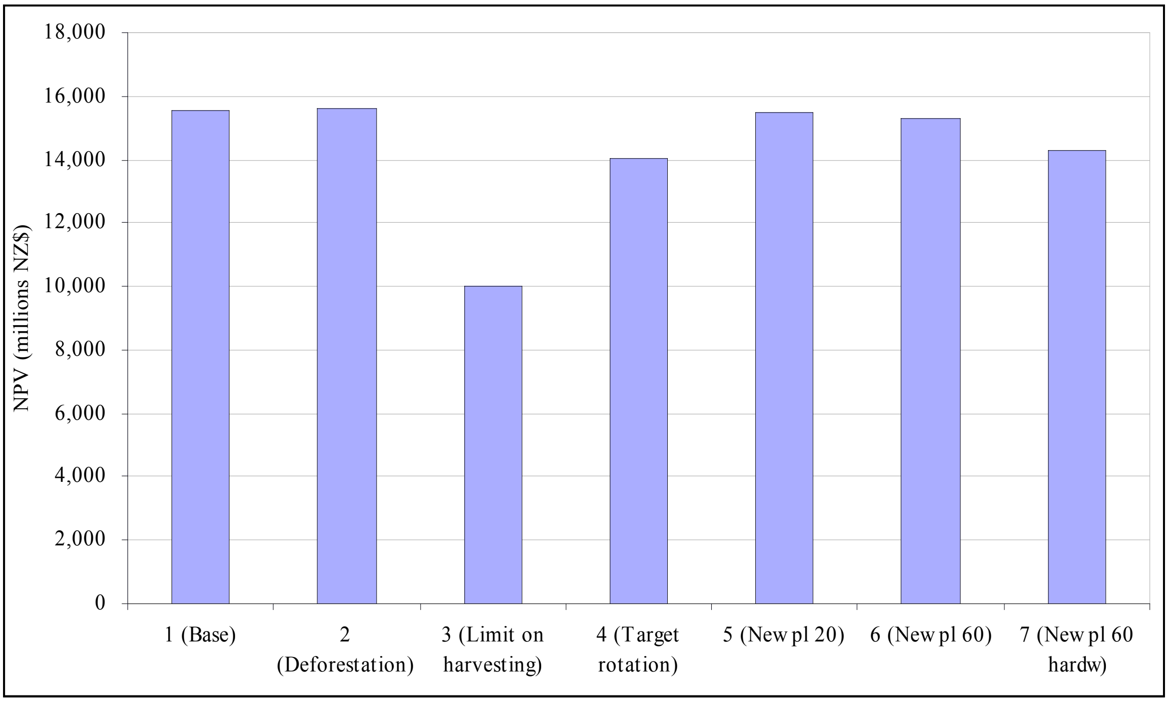

Figure 17. NPV for scenarios one to seven.

The NPV associated with each scenario compared to the base scenario (i.e. the relative change in NPV), the difference in NAE and the relative change in NPV divided by the relative change in NAE are presented in Table 12.

Table 12. NPV, NAE, NPV and NAE relative to base, relative NPV by relative NAE.

	NPV (million NZ$)	NPV relative to base	NAE (million tC)	NAE relative to base	Relative NPV / Relative NAE
1 (Base)	15,527	0	191	0	-
2 (Deforestation)	15,609	82	144	-47	-2
3 (Limit on harvesting)	10,009	-5,517	194	2	-2,411
4 (Target rotation)	14,049	-1,478	195	4	-364
7 (New pl 60 hardw)	14,294	-1,232	286	95	-13
5 (New pl 20)	15,467	-60	211	19	-3
6 (New pl 60)	15,317	-210	250	58	-4

The relative NPV divided by the relative NAE expresses the marginal economic benefit per unit of NAE ($/tC) compared to the base scenario. All scenarios showed negative values (Figure 18). Therefore, costs would be incurred in attaining higher net atmospheric exchange. The limit on harvesting scenario (4) showed the highest cost. If the objective is to achieve higher sequestration at a forest estate level, it became apparent that payments would have to be made. These results are consistent with Plantinga and Mauldin (1999) who furthermore showed, on the example of the US that these costs vary with site and region. In their study the marginal costs per tonne of carbon varied between 0 and 120 US$.

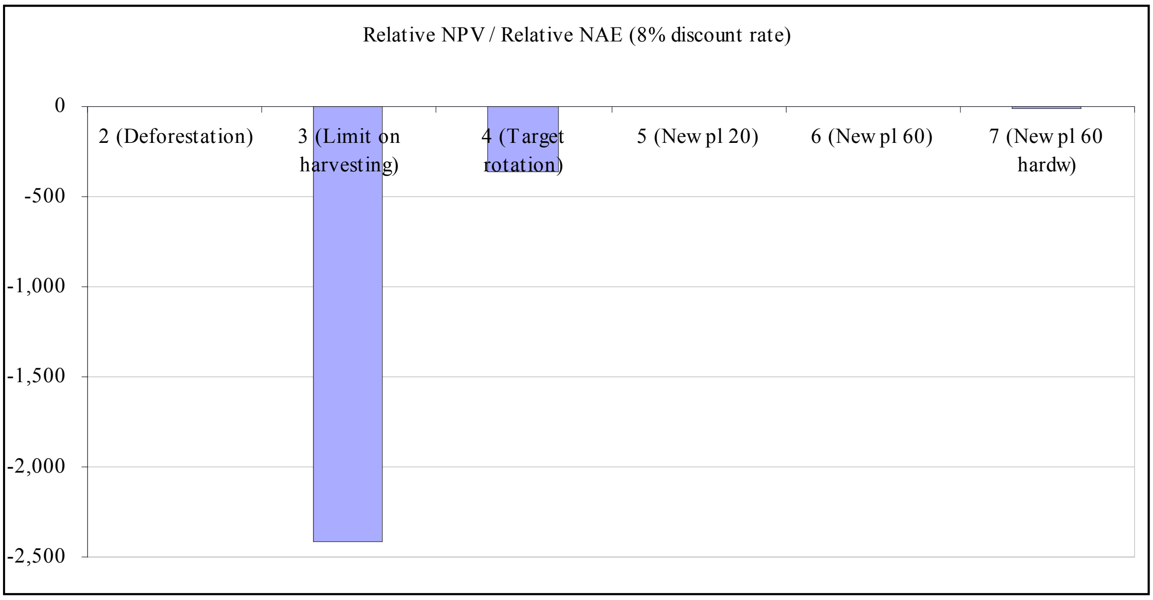

Figure 18. Relative NPV ($) to base per unit of relative NAE (tC) to base

Table 13. Present value of carbon balance, Carbon balance (discounted) relative to base, and relative NPV per relative carbon balance.

Scenario	Present value of balance (million tC)	Balance relative to base	Relative NPV / Relative Balance
1 (Base)	76		
2 (Deforestation)	39	-37	-2
3 (Limit on harvesting)	115	39	-143
4 (Target rotation)	103	27	-55
5 (New pl 20)	90	14	-4
6 (New pl 60)	121	45	-5
7 (New pl 60 hardw)	130	54	-23

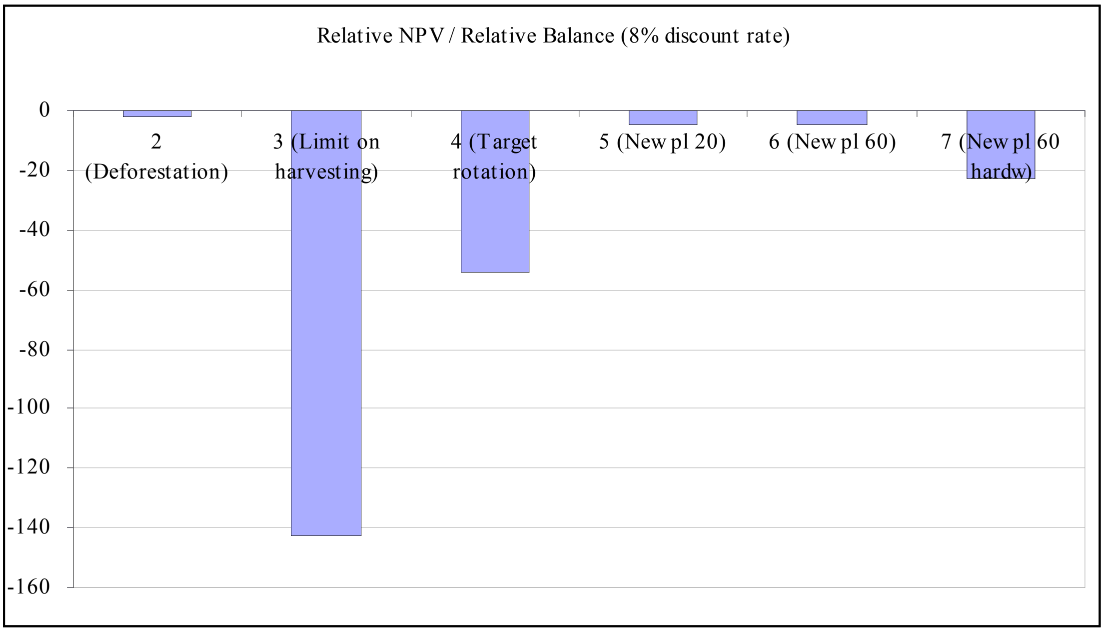

Figure 19. Relative NPV ($) to base per unit of relative balance (tC) to base.

2.5.5 Carbon Unit Value ($/tC)

In order to provide information on the value of carbon as an incentive for new forest plantings or avoidance of deforestation, the per unit carbon value was estimated at different land values (i.e. land cost or land revenue) for scenarios 2, 5, 6, and 7 (Table 14). Under the assumptions made in this study, each project would need to include an additional carbon value to make new planting or retention of forest profitable (i.e returns higher than 8%). Even on land with zero land value, a minimum additional carbon value was needed for new planting; otherwise the base scenario remained the most profitable.

The value of carbon needed to make new planting or avoiding deforestation more profitable varied depending on the planned type of forest estate. The lowest carbon unit value to make a change on the economics of mitigation options through land use management was $1.7/tC, at which level the retention of forest rather than deforestation would become profitable on land with zero value. In order to encourage new planting on the same type of land, at least $3.1, $3.6, and $13 per tC were needed in additional revenue for scenarios 5, 6 and 7, respectively. The higher the land value, the higher the carbon price necessary to increase the returns of the land use change to above 8%. These values of carbon are within and below the range of market prices that have been recently traded internationally. At some stages, the European carbon market have reached 30 Euros per tonne of emission unit allowance, therefore, is expected that after the start of the first commitment period the values will increase further.

Table 14. Carbon unit values ($/tC NAE) necessary to make new planting or avoiding deforestation profitable under different land prices.

	Scenarios			
land cost/revenue	**5(New pl 20)**	**6(New pl 60)**	**7(New pl 60 hardw)**	**2(Deforestation)**
0	3.1	3.6	13.0	1.7
1000	16.9	17.2	21.4	15.0
2000	30.6	30.8	29.7	28.2
3000	44.4	44.4	38.1	41.4
4000	58.1	58.1	46.5	54.6
5000	71.9	71.7	54.8	67.8
6000	85.7	85.3	63.2	81.1
7000	99.4	98.9	71.6	94.3
8000	113.2	112.5	79.9	107.5
9000	126.9	126.1	88.3	120.7
10000	140.7	139.7	96.7	133.9
11000	154.4	153.3	105.0	147.2
12000	168.2	167.0	113.4	160.4

By way of example it can be concluded that:

- In order to avoid deforestation and remain with the base scenario, it would be necessary to have an additional carbon value of at least $28.2 per tC at a land value of $2000/ha.
- In order to make new planting of 60 thousand hectares of hardwood profitable on land of the same value, it would be necessary to have a carbon price of at least $29.7/tC.

The trends of additional carbon values needed to make new planting profitable or deforestation unprofitable are illustrated in Figure 20. For lower levels of carbon unit values and land values up to $2000/hectare, avoiding deforestation and scenarios 5 and 6 appeared as the preferred mitigation options. However, for land values above $2000/hectare, scenario 7 was profitable at lower carbon values than the other scenarios. This is mainly a result of the high NAE achieved by this scenario compared to the base scenario.

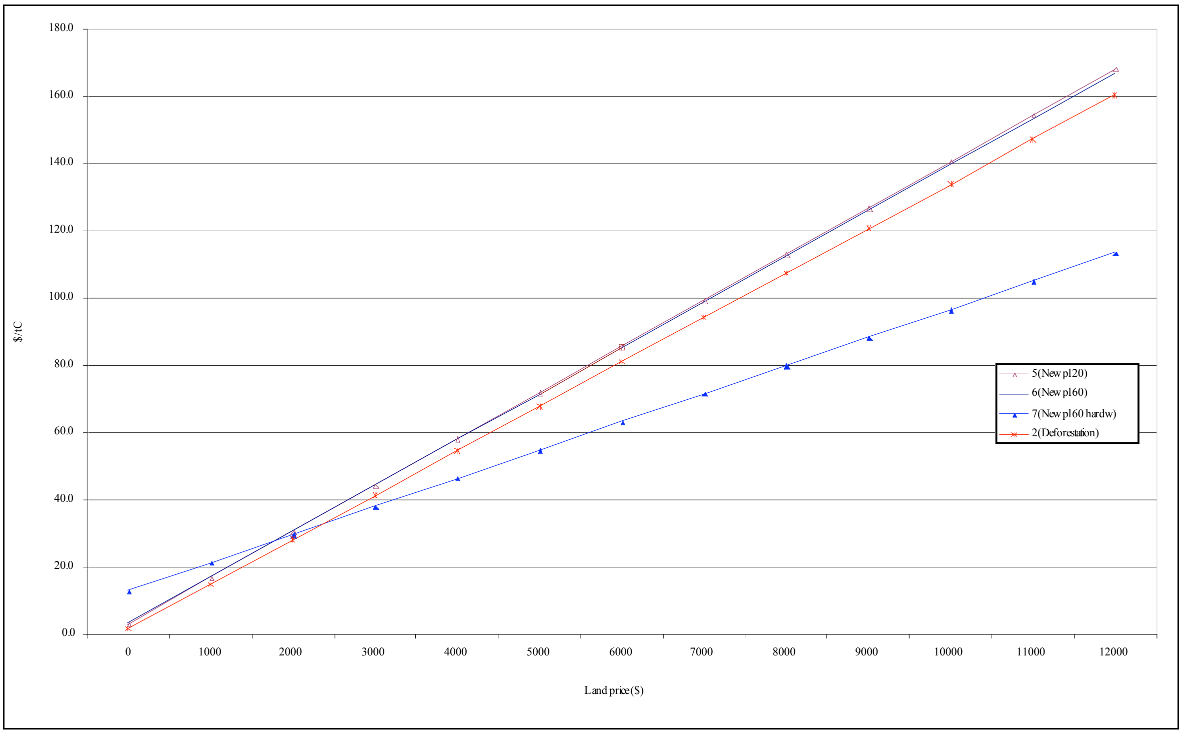

Figure 20. Carbon unit values ($/tC NAE) needed to make scenarios 2, 5, 6, and 7 profitable, depending on land value.

The effect of carbon benefits is not restricted to forest plantations and their carbon NAE, but extends to the whole forest industry. Thus, thresholds for carbon unit values were also calculated including the whole forest industry balance (Figure 15 and Figure 21). The lowest carbon unit value needed to make one of the modelled scenarios profitable was $2.1/tC, at which level deforestation may be avoided on land with zero value. New planting on the same type of land would be profitable with at least 4.1, 4.5, and $22.4/tC in additional revenue for scenarios 5,6, and 7, respectively. As with the previous estimates, the higher the land value, the higher the carbon price needed to increase the returns of a land use change to a level above 8%.

Table 15. Carbon unit values ($/tC Balance) needed for profitability of new planting and avoiding deforestation under different land prices.

	Scenarios			
land cost/revenue	**5(New pl 20)**	**6(New pl 60)**	**7(New pl 60 hardw)**	**2(Deforestation)**
0	4.1	4.5	22.4	2.1
1000	22.4	21.6	36.8	18.4
2000	40.6	38.6	51.2	34.6
3000	58.9	55.6	65.6	50.9
4000	77.1	72.7	80.0	67.1
5000	95.4	89.7	94.4	83.4
6000	113.6	106.8	108.8	99.6
7000	131.8	123.8	123.3	115.8
8000	150.1	140.9	137.7	132.1
9000	168.3	157.9	152.1	148.3
10000	186.6	175.0	166.5	164.6
11000	204.8	192.0	180.9	180.8
12000	223.1	209.1	195.3	197.1

Avoiding deforestation (i.e. scenario 2) appeared as the most profitable mitigation option at all land values except for the most valuable land above $11000/ha. Then scenario 7 became more profitable provided carbon value was set at above $180/tC.

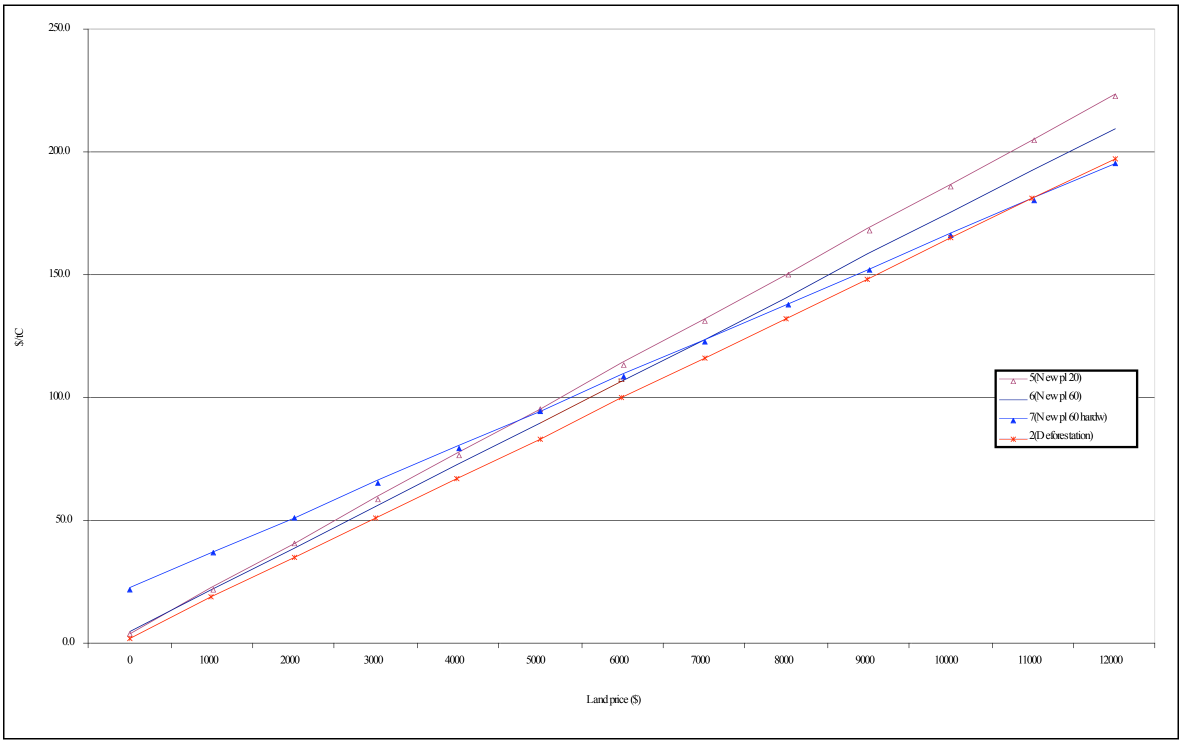

Figure 21. Carbon unit values ($/tC balance) for different new planted or deforested land prices

2.6 Conclusions

From the analyses described in this chapter and under the assumptions made in this study, the following conclusions can be drawn:

- **NAE vs Balance**. The ranking of the examined scenarios differs depending on the type of analysis undertaken. Both the NAE of forest plantations alone and the balance of the forest industry as an integrated system should be analysed before deciding on the most appropriate mitigation option to meet the expected objectives. New planting can be seen as a benefit to the atmosphere as it increases forest sinks and reservoirs. However, factors such as log allocation and end-use of products among others affect the carbon balance in a way that a new planting strategy could result in decreasing the mitigation potential of the industry as a whole.
- **Long term NAE**. If the objective is to maximise forest carbon sequestration, the new planting scenarios (7, 6 and 5 respectively) are the best mitigation options. Increasing the target rotation age does not provide as much benefit as the new planting scenarios but is a better option than setting a limit on harvesting. Deforestation should be avoided as it is not a sink and increases emissions.
- **Long term balance**. If the objective is to maximise the carbon benefits of the entire forest industry new planting scenarios with the same croptypes (i.e 5 and 6) are the best mitigation option. The new planting hardwoods scenario decreases the carbon balance of the forest industry compared to the base case. The limit on harvesting provides less mitigation benefit than increasing the target rotation or the base case. Therefore, there is no incentive to limit the harvesting volume. Deforestation has a negative balance thus should be avoided.
- **NAE for limit on harvesting vs target rotation scenarios**. Letting the forest grow and reach maturity without harvesting, reduces the potential benefit of the forest to the atmosphere (even thought is still a reservoir). Changing the management from the base scenario to longer rotation is beneficial to the atmosphere while the limit on harvesting showed a decreasing benefit and a negative impact compared to base.
- **Balance for limit on harvesting vs target rotation scenarios.** Changing the national forest estate to longer target rotation ages aiming at higher carbon benefits has positive results while limits on harvesting volume has negative results.
- **Net present value (NPV).** All scenarios except deforestation showed negative relative NPV to base, and hence it would not be economically viable to change the forest estate

from base to any of the possible scenarios analysed. Additional revenues or incentives that increase the return are needed if any of the possible scenarios are considered necessary.

- **Additional carbon value**. The carbon price necessary to increase the returns of the land use change to a level equal or above 8% increases when land value increases.
- **Economic incentives to preferred mitigation options**. The new planting area with the same croptypes and avoiding deforestation would be the preferred mitigation option in land values below $2000/ha. However, for land values above $2000/hectare, new planting area with hardwoods will need the lowest carbon value per unit of carbon sequestered (NAE) than other scenarios and is thus the preferred mitigation option. When the unit of carbon balance was valued, avoiding deforestation on land valued up to $11000/ha is the cheapest mitigation option to incentivise. In land valued above that level, new planting with hardwood would be the cheapest scenario to incentivise.

CHAPTER 3. Energy Use, Bioenergy and the Carbon Balance of the Forest Sector

There are many potential options for how the increase in volume harvested can be used. It is possible that the future industry may be similar to the current but with more processing mills. The impact on the industry energy use would be to increase consumption and hence carbon emissions. Another option would be to focus on highest value products such as sawn timber for the additional harvest. In the absence of competing markets (i.e. pulp or board mills) the residues from forest plantations and sawmills could be used to produce energy. All this material has energy potential and additionally, if used for bioenergy there are emissions that may be avoided through the substitution of fossil fuel use. All these factors will in turn affect the carbon balance of the entire industry.

The New Zealand forest industry as a whole consumed 69 PJ of energy in 2002, of which approximately 50% (i.e 36.6 PJ) was generated internally, primarily through the use of black liquors from the pulp sector and wood processing residues such as bark, reject chips and fines (Anderson *et al.* 2003). Wood and wood products can be utilised to produce energy (as heat, electricity, liquid fuels etc) through different conversion routes. In New Zealand it could be argued that biomass fuels would be used to avoid fossil fuel use. There are, of course, economic constraints to utilisation of all wood wastes, and there are also environmental ones.

One of the objectives of this study was to assess a combination of mitigation options through land use management, forest industry and bioenergy aimed at reducing GHG emissions for the short and long term. The effect of land use change and management on the net atmospheric exchange and the carbon balance was analysed and discussed in the previous chapter. However, the previous sections did not consider the GHG implications of converting from forestry to another land use e.g. emissions from cropping or grazing, or the impact of indirect fossil fuel substitution i.e. the use of wood rather than alternative non-wood products that tend to be more energy intensive to produce.

This chapter looks at the impact of other variables within the carbon balance such as log allocation to the forest processing sector, and proportions of processing residues removed from site and used for bioenergy. All these variables have a direct impact on energy use and hence, emissions arising from the sector that will affect the carbon balance. Additionally, the New Zealand carbon balance is affected by the temporal profile of emissions (i.e. instant or delayed emissions), the boundaries (i.e. domestic vs export emissions) and emissions avoided by direct substitution (i.e. biomass substituting fossil fuel use).

The forest sector has the potential to supply other biomass sources than processing residues only, such as forest residues, or short rotation crops for energy. The analysis only looks at the effect of an increase in the proportion of logs processed domestically, rather than exported in an unprocessed form, and an increase in the proportion of processing residues used for energy. The supply of woody biomass used for bioenergy and the use of biomass in New Zealand, as well as barriers identified as a constraint to increase bioenergy use are also presented in the following sections.

3.1 Woody Biomass Supply for Bioenergy and Use of Biomass in New Zealand

A forest industry produces considerable volumes of 'waste'. Much of this material could be viewed as an energy resource. In the forest, wood from prunings, thinnings and harvesting residues are either left in the forest to decay, or is burned to waste. Forest processing industries vary in their conversion ratios, but in some cases mill waste is utilised on site. Sawmill waste can be sent to board mills and/or pulp, and different products can also be used after a useful life to make other products and finally there is the bioenergy option for unusable biomass.

There are four main potential sources of woody biomass: (i) material arising from thinning and clearfelling operations; (ii) fuelwood from integrated harvesting regimes; (iii) plantations grown for energy such as short rotation crops and firewood recovery; and (iv) residues from processing of timber (New Zealand Energy Efficiency and Conservation Authority and University of Canterbury Centre for Advanced Engineering 1996). The supply of woody biomass resources and the variables that affect these resources are shown in Figure 22.

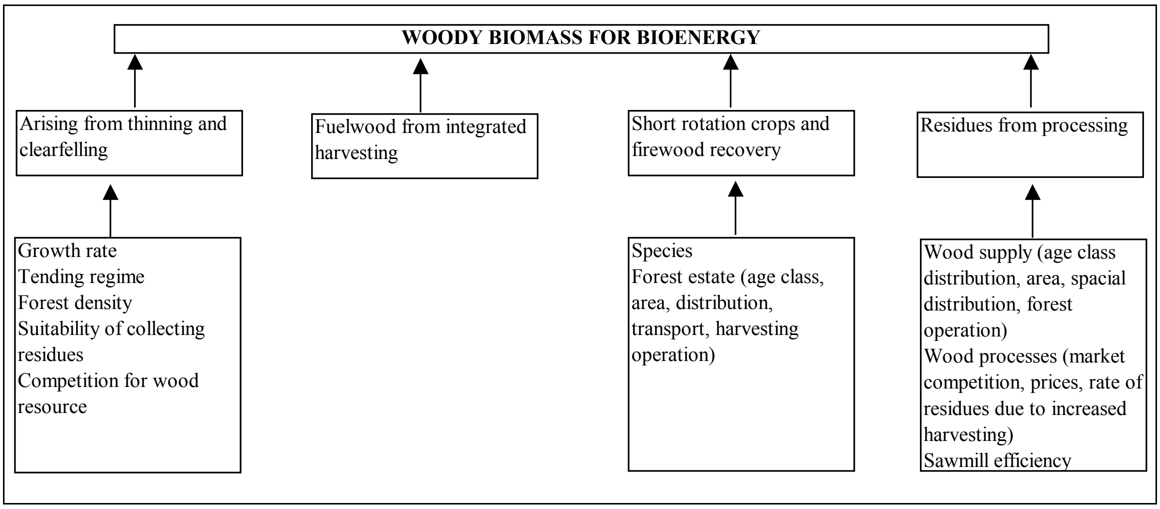

Figure 22. Sources of woody biomass for bioenergy and factors governing their supply

Source: (EECA 2001a)

Material arising from the forest is the unmerchantable above-ground biomass left on the floor after harvesting. The harvesting system used will largely determine the amount of biomass that can be recovered and used for bioenergy. Harvesting residues can be left on site after clearfelling, comminuted at the stump and extracted to the landing or central plant where they will be processed (New Zealand Energy Efficiency and Conservation Authority and University of Canterbury Centre for Advanced Engineering 1996). Whole tree comminution produces only wood for fuel and not other products, as would be the case with thinnings and short rotation crops. Factors affecting availability of these residues for energy are: (i) growth rate, age class, tending regime and harvesting practices; (ii) spatial distribution of forest areas; (iii) suitability of collecting residues from different areas and off steep terrain and (iv) competition for wood resource (EECA 2001a).

Integrated harvesting systems combine stemwood and fuelwood into one operation, extracting the entire tree, roundwood is recovered, and tops and branches comminuted to wood fuel.

Short rotation crops (SRC) for bioenergy or short rotation forest energy plantations are plantations grown specifically for energy purposes, where the aim is to produce the maximum biomass from the site (Matthews and Robertson 2002). They are often grown in association with the land treatment of sewage and industrial effluents. Firewood usually comes from land clearing, harvest residues (usually at landing), small sawmill residues, wind thrown trees and other small residues.

Wood processing residues consist of bark, sawdust, shavings, slabs, dockings, and offcuts, from both primary processors, which generates about 90% of the total residues, and secondary processors (New Zealand Energy Efficiency and Conservation Authority and University of Canterbury Centre for Advanced Engineering 1996). Costs of supplying wood process residues would depend on: (i) supply and demand for material for energy or alternative uses; (ii) the nature of residues; (iii) proximity of processing facility to the energy plant; and (iv) the need for pre-processing the material before using it in an energy plant (EECA 2001a).

Woody biomass availability in New Zealand, except from energy plantations, can be limited by factors such as age class and species distribution of forested areas, structure of forest operations and log markets, transport systems and network constraints, and competition between the wood fibre industry and energy uses (New Zealand Energy Efficiency and Conservation Authority and University of Canterbury Centre for Advanced Engineering 1996).

In New Zealand, commercial use of biomass for bioenergy mainly occurs in the pulp and paper industry by the use of black liquor and use of wood process residues for heat production and cogeneration (EECA 2001a). The bioenergy market is focused on heat, as electricity production from bioenergy is not currently economic, and is even only occasionally economic in a cogeneration situation. While the economics of cogeneration of electricity will become more financially attractive as electricity prices increase, it is unlikely that production of electricity alone from biomass will be economic for some years. Fifty percent of the capital cost of a bioenergy heat plant is in the boiler with the remainder in fuel storage and handling. There is little need for improvement in boiler plant as this technology is well proven and is available. Substantial experience and development is needed in fuel handling and storage to improve performance and to reduce costs (East Harbour Management Services 2002).

Total processing residues have been estimated by Sims (1993) and by Ford-Robertson (1995) for Northland and East Coast. They have suggested that processing residues are 40% of total roundwood processed. There is competition for the use of residues for pulp and board industry. Pulp and paper operations are located in the CNI and Hawkes Bay, whereas panel production facilities are in Kaitaia, Auckland, Thames, CNI, Gisborne, Masterton, Nelson and Canterbury (EECA 2001a). Therefore, competition with these markets would be regionally specific**.** The potential competing market such as a fibre processing mill and waste disposal and supplies of wood has been addressed by Ford-Robertson (1995).

The forest harvesting and wood processing industries are moving towards adoption of higher quality processing (Anderson *et al.* 2003). This often necessitates residue removal from the site providing an opportunity for use in bioenergy plants. There are real opportunities to expand forestry businesses with an emphasis on increased processing as the mature forest estate increases over the next decade. New or expanded processing facilities could include biomass conversion technologies at the planning stage. Wood processors are increasing the quantity of value added products being produced in New Zealand. This produces more residues but also increases the demand for on-site heat and electricity.

There appears to be some immediate possibility of co-firing coal and biomass for timber drying. However this opportunity is limited as the coal contribution to the total energy now used for drying is only 15 % of total. The cost of wood processing residue disposal in landfills creates an opportunity for bioenergy, and enhances the profitability of any plant consuming that residue on site. Advanced biomass conversion technologies are now maturing with increasing numbers of large demonstration projects establishing technical feasibility.

A major incentive for change comes from the negative direction the energy industry is taking with respect to the use of renewable energy sources generally, and woody biomass in particular. Since the Kyoto Protocol was negotiated and 1990 emissions set as the baseline, energy demand has continued to grow, with the proportional contribution from renewable consumer energy shrinking (EECA 2006). This applies to both electricity generation and industrial heating (particularly timber drying) with gas and coal tending to displace renewable sources as demand grows.

3.2 Carbon Balance National Level Scenarios Sensitivity Analysis

The carbon balance (tC/yr) over time and the present value of carbon balance for the 'base' scenario were presented in Chapter 2. In this section they are compared to the values attained with different log allocation and processing residues from sawmills used for bioenergy.

In the base scenario the current and additional harvested volume were allocated to market destinations as illustrated in Table 2.

The assumptions made for the base scenario are described in section 2.3.8. Regarding the use of processing residues, it was assumed that only 10% was available and used for bioenergy, while residues left on site decayed at a 20% annual decay rate. These assumptions lead to the carbon balance illustrated in Figure 10 of section 2.5.3.

The log allocation analysis, in which an increase in domestic processing was simulated, the boundaries of the scenario and thus the allocation of emissions and the temporal profile are affecting the carbon balance. In this study was assumed that harvested wood product emissions were allocated to the producer country. However, export emissions decayed instantly whereas emissions from products processed onshore were delayed over time.

3.2.1 Log Allocation and Use of Residues for Bioenergy

The 'base' scenario (1) was used to perform the sensitivity analysis of: (i) log allocation for the additional volume produced (i.e. above 19 million m^3) and (ii) higher proportion of processing residues used for bioenergy, on the carbon balance.

Log allocation for additional volume. Some log types of radiata pine additional[5] harvested volume (i.e S1S2 and S3L3 logtypes) were allocated to sawmill processing

[5] Additional volume was the volume harvested above 19 million cubic meters.

instead of exports, to assess the impact of the increased volume harvested on the energy use, emissions, and hence, the carbon balance. The new allocation is presented in Table 17. This scenario represents a major shift away from log exports towards domestic processing.

Table 16. Percentage of the additional harvested volume, over and above 19 million m3, of radiata pine logs going to a particular end use".

RADIATA	Export	Ch.Pulp	Mech.Pulp	Sawmill	Veneer	Particleboard	Fibreboard
Pruned logs	0%			95%	5%		
S1S2	0%			95%	5%		
S3L3	23%	14%	5%	50%		4%	4%
L1L2	65%	14%	5%	10%		3%	3%
Pulp logs	0%	45%	15%			20%	20%

Given the assumptions made in the model, this leads to an increase in energy use and processing residues, and a decrease in instant emissions from export logs. The higher carbon balance (tC/yr) that resulted from the additional volume being allocated to sawmills is illustrated in Figure 23.

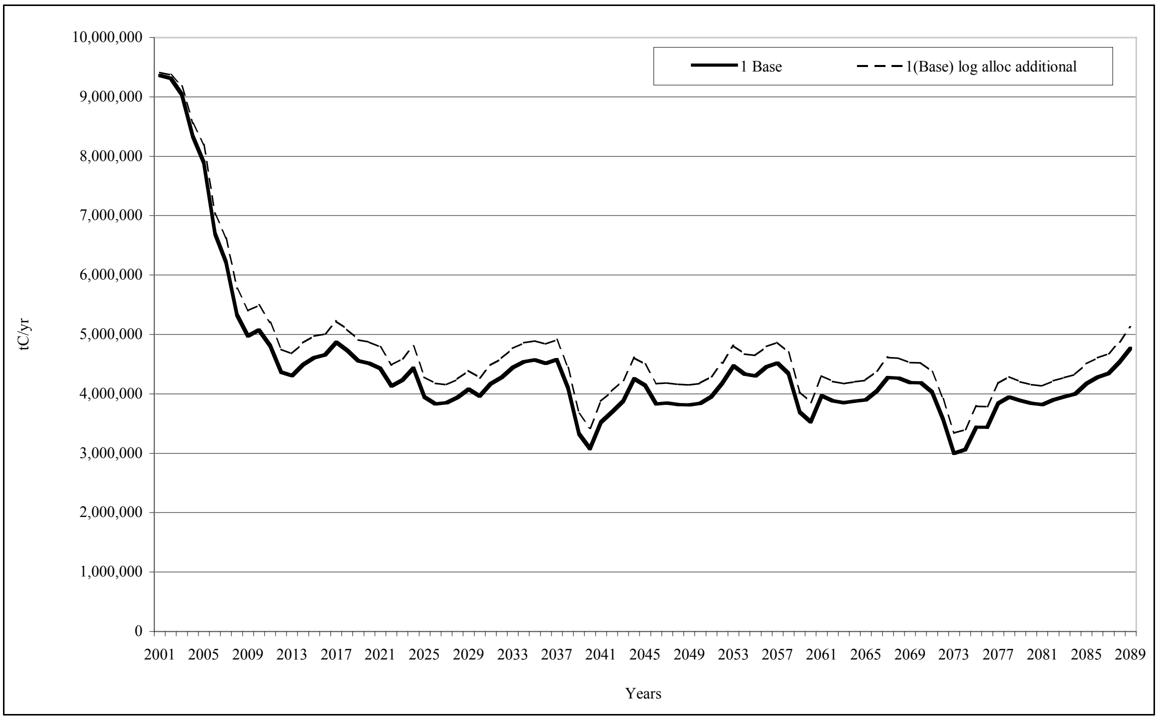

Figure 23. Carbon balance (tC/yr) for base scenario and the scenario with different log allocation to additional volume.

The present value of carbon balance was estimated to be 80 million tC under the scenario with different log allocation. The present value of the base scenario was 76 million tC (Table 10), and hence the relative change on the present value of carbon balance was approximately 4 million tC. There was a net benefit to the atmosphere when the industry focused on highest value products (i.e. greater domestic processing) compared to exports.

The NAE for both scenarios remained the same, since there was no change on the national forest estate. The difference between both balances was due to higher total emissions from energy use for processing, and processed or exported harvested wood products (Figure 24 and Figure 25).

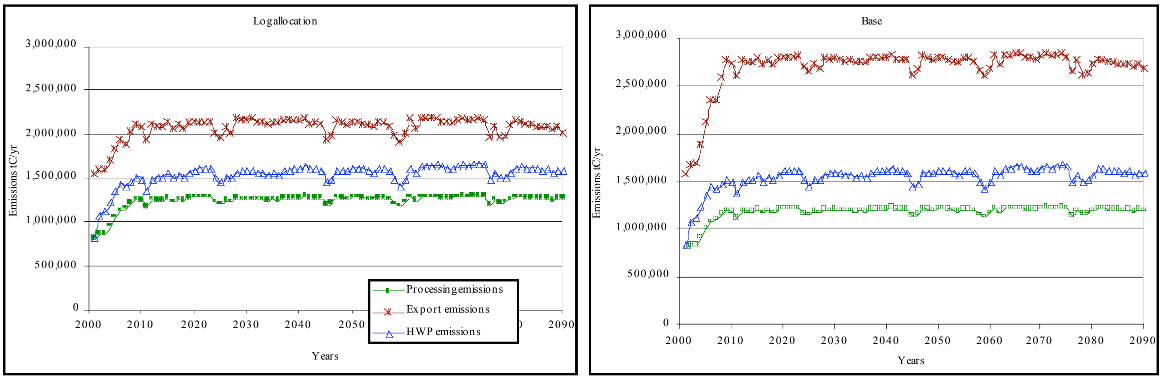

Figure 24. Emissions from processing, HWP and export logs for base scenario and the ‘’log allocation’’ scenario (i.e. higher sawn timber produced).

In the base scenario the baseline scenario it was assumed that instantaneous emissions occurred from logs that were exported. However, when these logs were processed domestically and allocated to a sawmill, emissions arose from processing, harvested wood products and processing residues decaying on site and used for bioenergy. Using a conservative approach_to account for export logs (i.e. allocating responsibilities to the producer country and assuming instantaneous emissions), leads to a positive relative balance if processing occurs onshore. Some emissions such as those from harvested wood products and processing residues are delayed, and hence the result was a better short and long term balance for the whole industry shown in Figure 23.

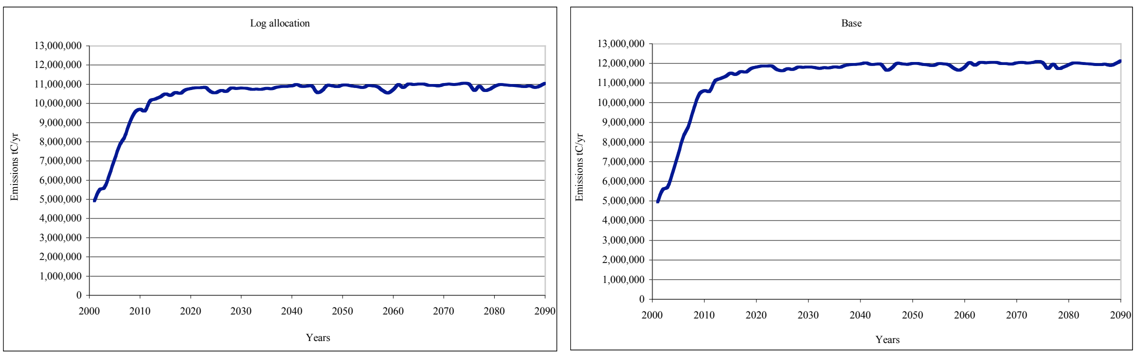

Figure 25. Total emissions for base scenario and the ‘’log allocation’’ scenario (i.e higher sawn timber produced).

This log allocation scenario could be considered as the difference between using harvested material for bioenergy (instant emissions) or products (delayed emissions). It is therefore evident that it is preferable from carbon balance perspective to use harvested wood for products. The scenario does not prevent the products being used for energy one they have served a useful life.

Processing residues used for bioenergy. The effect of higher proportions of sawmill residues used for bioenergy on the carbon balance was assessed, assuming that there was an increase in residue use from 10% to 20, 50 and 100%. The higher use of residues for energy the earlier emissions occur. This results in a lag between the carbon balance using higher proportion of residues compared to the base scenario (Figure 26) in which only 10% of sawmill residues were used for bioenergy. The higher the proportion of residues used for bioenergy, the lower the carbon balance in the short term, becoming equal in the long term (i.e. after emissions from residues decaying stabilises). When the emissions occur is the only difference between both scenarios, since they have different profile but the same amount of emissions is accounted for.

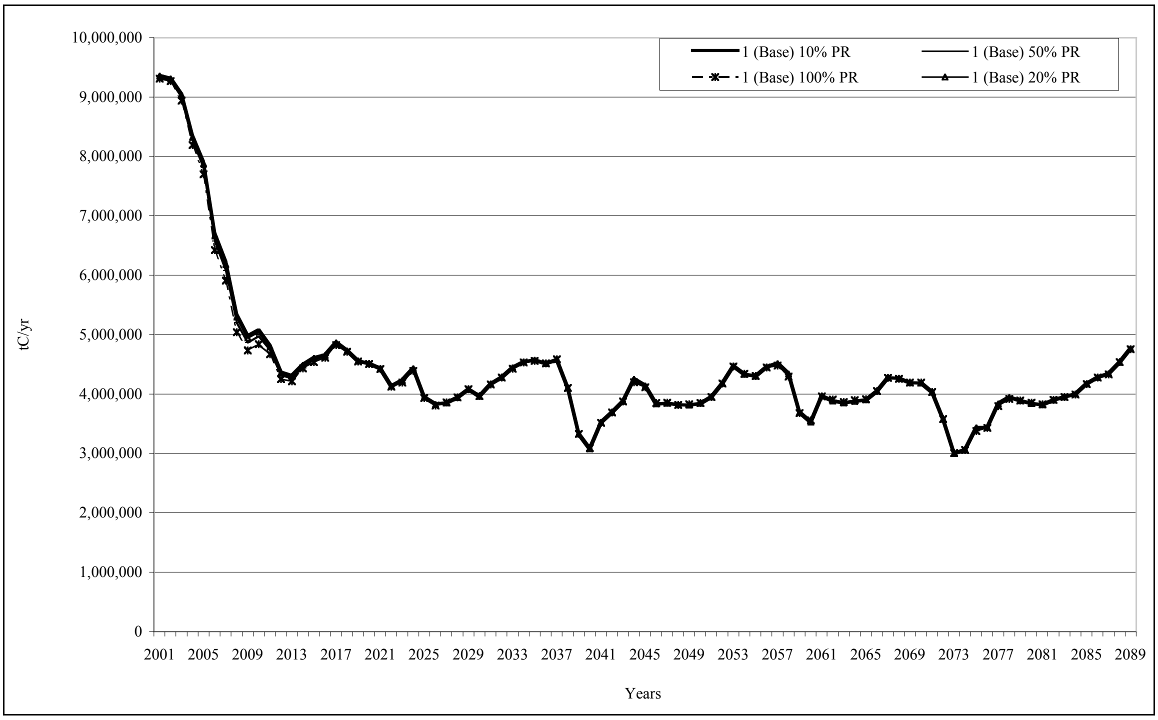

Figure 26. Carbon balance (tC/yr) over time for the base scenario (10% of processing residues use) and with 20, 50 and 100 % of processing residues use.

The present value of carbon balance and the relative value to base scenario was also estimated (Table 18). The present values of the balance were lower than the base scenario, and hence the relative values of balance to base were negative when higher processing residues were used.

Table 17. Present value and relative balance to base assuming different proportions of processing residues used for bioenergy.

Scenarios	**Balance discounted (million tC)**	**Balance relative to base**
1 (Base) 10% PR	76	
1 (Base) 20% PR	76	0
1 (Base) 50% PR	75	-1
1 (Base) 100% PR	75	-1

The lower carbon balance observed when processing residues were used for bioenergy, is a result of the temporal profile and the effect of discounting on the short term emissions. As was described in section 2.3.8 residues left on site decayed over time at a 20% annual decay rate. However, when these residues were used for bioenergy an instant decay rate was applied and hence there were higher emissions early on.

Given this carbon accounting method (i.e. 20% decay rate if left on site and 100% decay if used for bioenergy), from the short term carbon balance point of view, it would be beneficial not to use residues and leave them on site to decay over time, and hence delay emissions rather than using them for bioenergy. This issue cannot be analysed in isolation by only looking at the carbon benefits, since there are other implications and benefits of using a renewable resource available that can be used to produce energy rather than being wasted instead. Additionally, these resources can substitute fossil fuel use and improve the energy self-sufficiency of the sector as well as the carbon balance.

One way to illustrate these benefits of residues used for bioenergy is to analyse the emissions that would be avoided for every tonne of carbon contained in biomass and used for bioenergy. Additionally, there is potential energy that can be produced from these residues, whether to substitute fossil fuels or to meet future energy demand instead of using the same energy source currently being used. These implications will be addressed and discussed in the following section 3.2.2 and 3.2.3.

The balance analysed for different log allocation and processing residues used was compared to the balance under different national forest estate scenarios (Table 19, Figure 27 and Figure 28). Deforestation was the worst scenario in terms of carbon balance (i.e. negative impact to the atmosphere), followed by the scenarios with higher proportions of processing residues used for bioenergy. The scenario with the industry focused on highest value products and domestic processing (i.e allocation of harvested volume to sawmill) and the scenarios of new planting rates, longer rotation age and limit on harvesting had positive impact on the atmosphere. The effect of changing log allocation was small compared to the forestry option. The direct impacts on the forest are likely to be more than those further downstream. However, factors such as decay rate of HWP would affect these results.

Table 18. Present value and relative balance to base for all scenarios analysed

Scenarios	**Balance discounted (million tC)**	**Balance relative to base**
1 (Base)	76	
2 (Deforestation)	39	-37
3 (Limit on harvesting)	115	39
4 (Target rotation)	103	27
5 (New pl 20)	90	14
6 (New pl 60)	121	45
7 (New pl 60 hardw)	130	54
1 (Base) 20% PR	76	0
1 (Base) 50% PR	75	-1
1 (Base) 100% PR	75	-1
1 (Base) log allocation	80	4

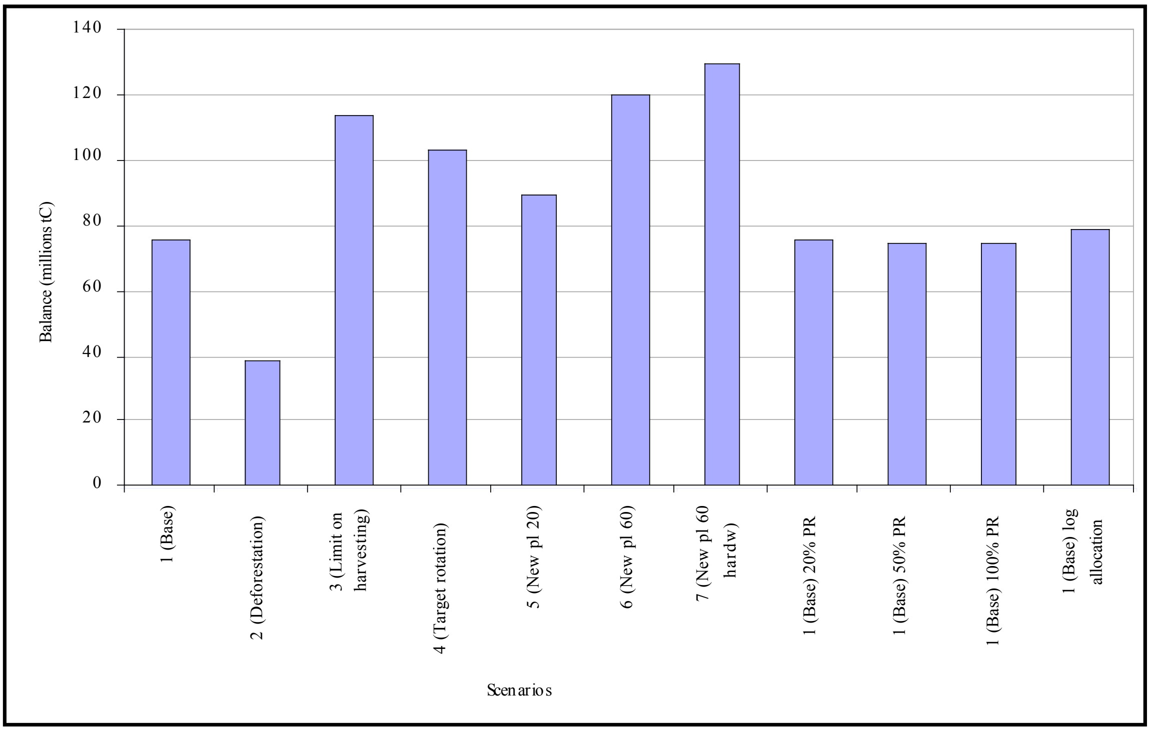

Figure 27. Range of present balance (tC) for all scenarios.

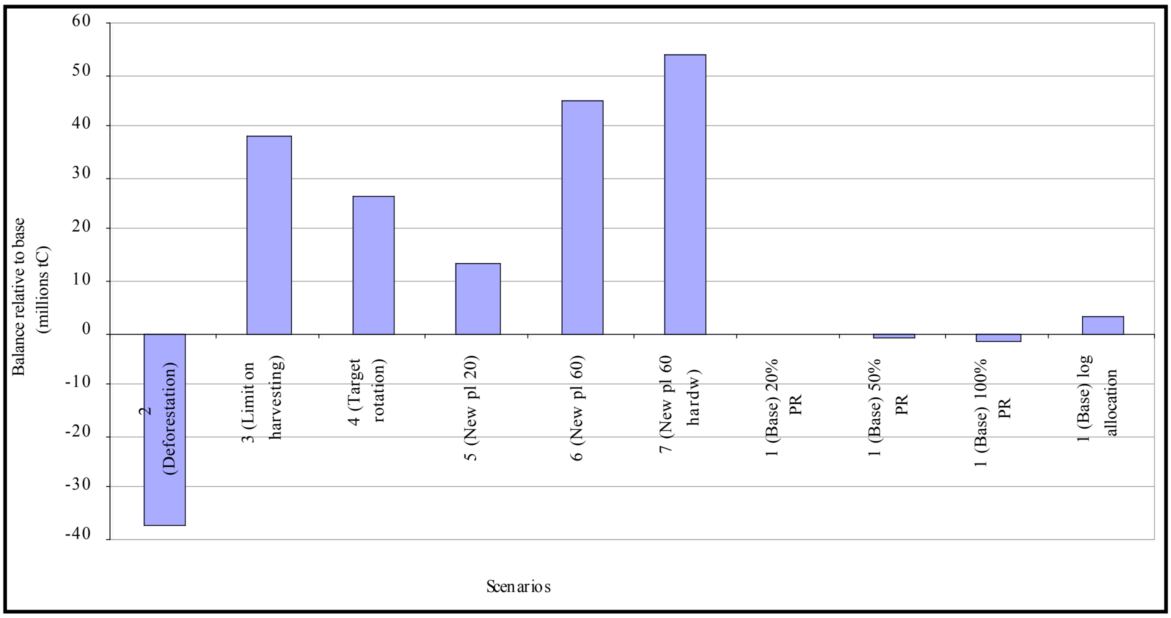

Figure 28. Range of relative balance to base for all scenarios

3.2.2 Emissions Avoided

Schlamadinger (1996) defined displacement factors that describe direct fossil fuel substitution. These displacement factors have units of MgC *''and represent the net amount of fossil fuel C not oxidized because 1 MgC in biomass is used for energy or is stored in wood products''*. The displacement factor for fossil fuel (Df) was defined as:
Df = (efficiency of bioenergy system/ efficiency of displaced fossil system) x (C emission per J of fossil fuel/ C emission per J of biofuel)

With current technology 1 Mg of C in wood fuel can displace about 0.6 Mg of C in fossil fuel (Schlamadinger and Marland 1996). Marland *et al.* (1997) also uses a displacement factor of 0.6 for fossil fuel substitution.

In this study, the displacement factor of 0.6 was used to estimate emissions from fossil fuels that can be avoided if processing residues were used for bioenergy. The approach is based on the assumption that if processing residues are used instead of being ''wasted'', they can eventually avoid fossil fuel use, whether substituting energy currently being used or to meet the increasing demand of energy. For every tonne of carbon in wood fuel (i.e processing residues from sawmill in this case) 0.6 tonnes of carbon in fossil fuel emissions would be avoided. This implies that only 40% of the carbon contained and emitted from processing residues used for bioenergy will be accounted for in the total emissions from processing residues. This results in lower total emissions from processing residues (Figure 29 and Figure 31) thus better carbon balance.

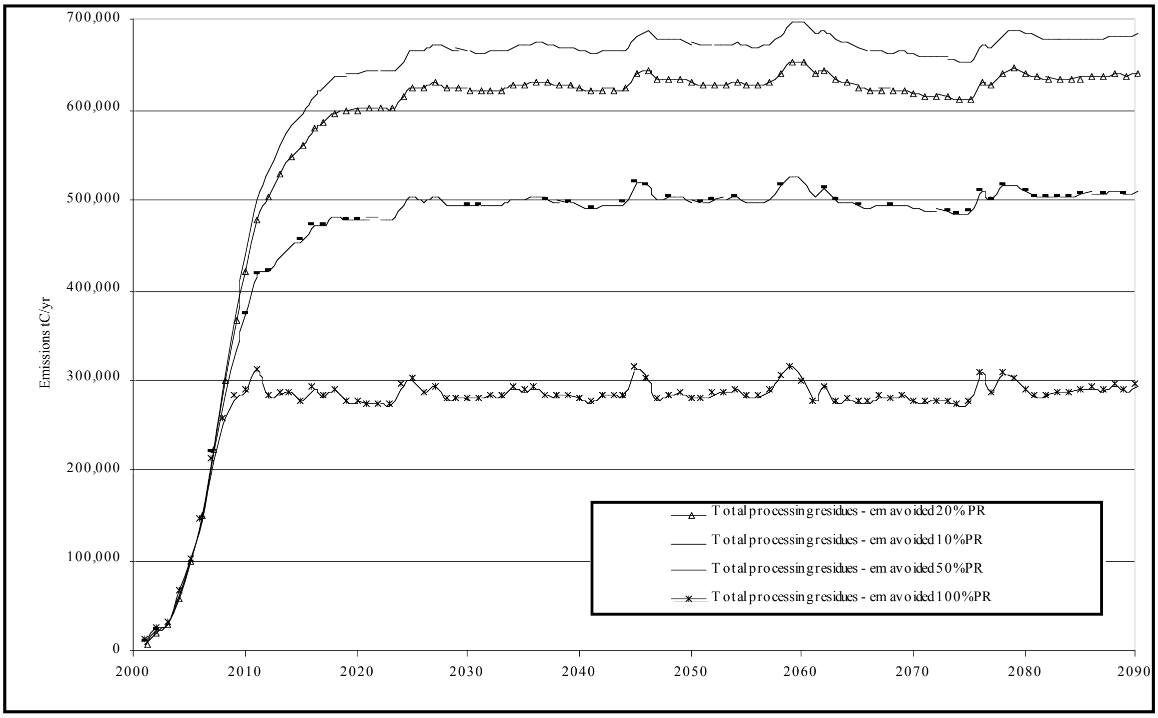

Figure 29. Total processing residues emissions (i.e decaying on site and from bioenergy) minus emissions avoided[6].

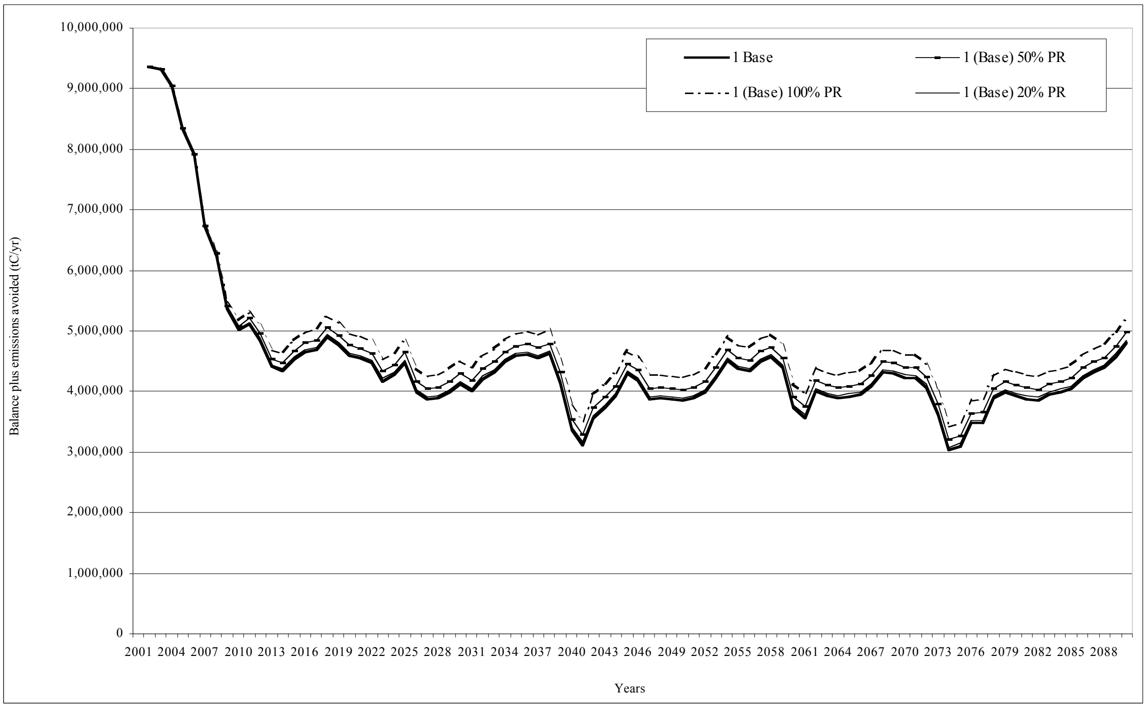

Figure 30. Carbon balance (tC/yr) including emissions avoided through substitution of fossil fuels by bioenergy from processing residues.

6 PR means processing residues.

The higher the proportion of residues used for bioenergy the lower the total emissions accounted for in the carbon balance, since there are more emissions avoided (Figure 29).

This is the result of a balance between a decrease in emissions from decaying residues and an increment in emissions from bioenergy. Under this scenario there would be emissions from fossil fuel being avoided (i.e equivalent to 60% of bioenergy emissions that will avoid fossil fuel use and hence emissions), which results in a reduction of all processing residues emissions.

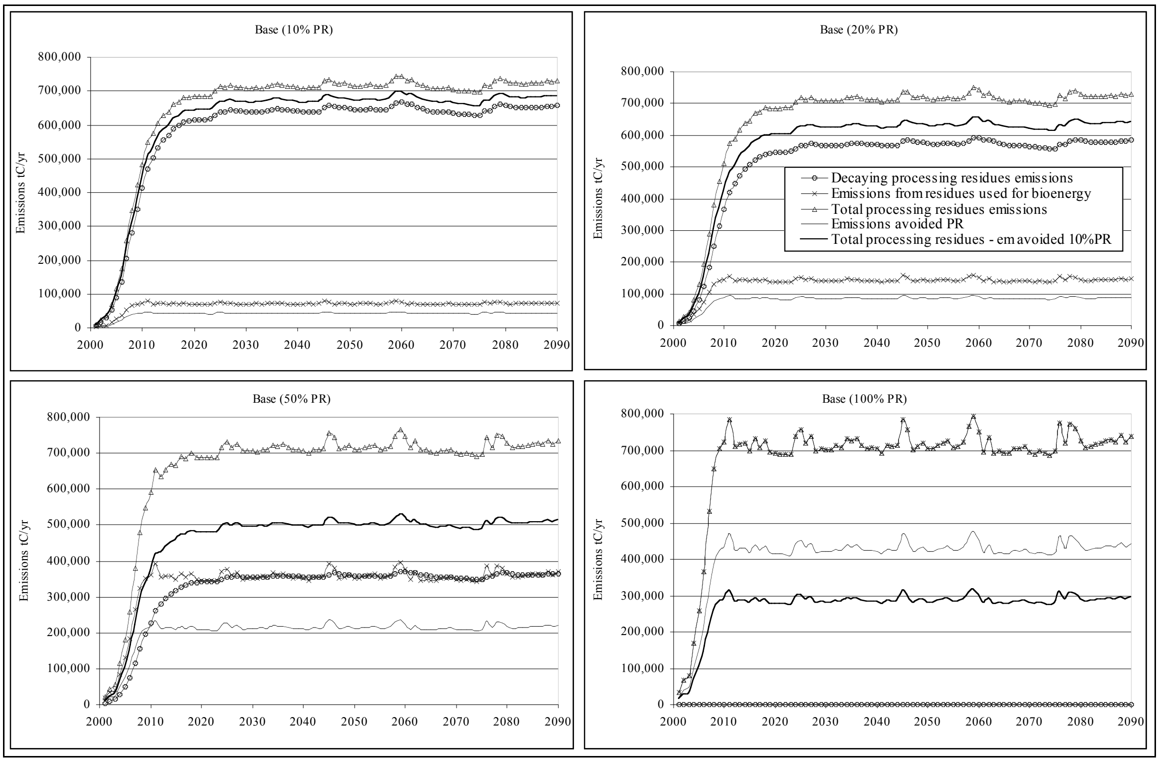

Figure 31. Processing residues emissions (i.e decaying and used for bioenergy), emissions avoided if bioenergy substitute fossil fuel, and total processing residues emissions minus emissions avoided.

Increasing processing residues used for bioenergy in order to substitute fossil fuel use, shows a net benefit to the atmosphere that has been seen through a better carbon balance than lower proportion of processing residues used for bioenergy. Additionally, New Zealand would have other benefits for using residues, such as the potential energy that can be generated from the residues available. This would improve the energy supply in many areas that are currently energy-constrained and increase national energy self-sufficiency. There is potential for the forest processing sector to be a net energy exporter, conferring substantial energy cost savings, reduced risks due to potential energy crises, and potential marketing advantages. The following section analyses the energy potential of sawmill residues for the base scenario.

3.2.3 Energy Potential

The energy potential (*E*) of sawmill residues (GJ) was estimated from the following equation:

$$E = \rho V C$$

where ρ is average wood density (tonnes/m3), V is the residue volume (m^3) and C is the calorific value of oven-dry wood (GJ/t). A calorific value of 19 GJ/t was assumed (Forest Research, unpublished data). The average wood density assumed was 0.425 tonnes/ m^3

The energy demand from each processing sector (i.e combined output for all plants of the same ''sector'') was estimated to assess how much of these energy would be met by the energy potential of residues. The energy needs for each processing plant to process the harvested volume simulated in the 'base' national estate models in Chapter 2 was the result of tonnes or m^3 of products times energy intensity in GJ/tonne or m^3 of product. The energy intensity values used for different products were 34.51 for chemical pulp, 9.81 for mechanical pulp, 1.93 for sawntimber, and 4.31 for panels (Table 6). The energy demand by processing sector and the energy potential of different proportion of residues over the whole period modelled are presented in Appendix V.

The energy potential of different proportions of processing residues[7] was estimated and compared to the energy demand of the sawmill sector (Figure 32). Using 100% of processing residues generated by the sawmill sector would be enough to meet their energy demand and would also have an excess of energy to commercialise. Under these circumstances, the sawmill sector would be self-sufficient, a net exporter of energy, potentially avoid emissions from fossil fuel, reduce costs from waste disposal to landfill, reduce risks and uncertainty of energy supply.

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[7] The proportions of residues components (bark, slab, etc) were not considered. The proportion of each component vary between plants, species, etc. Data from each plant was not available and averages were used.

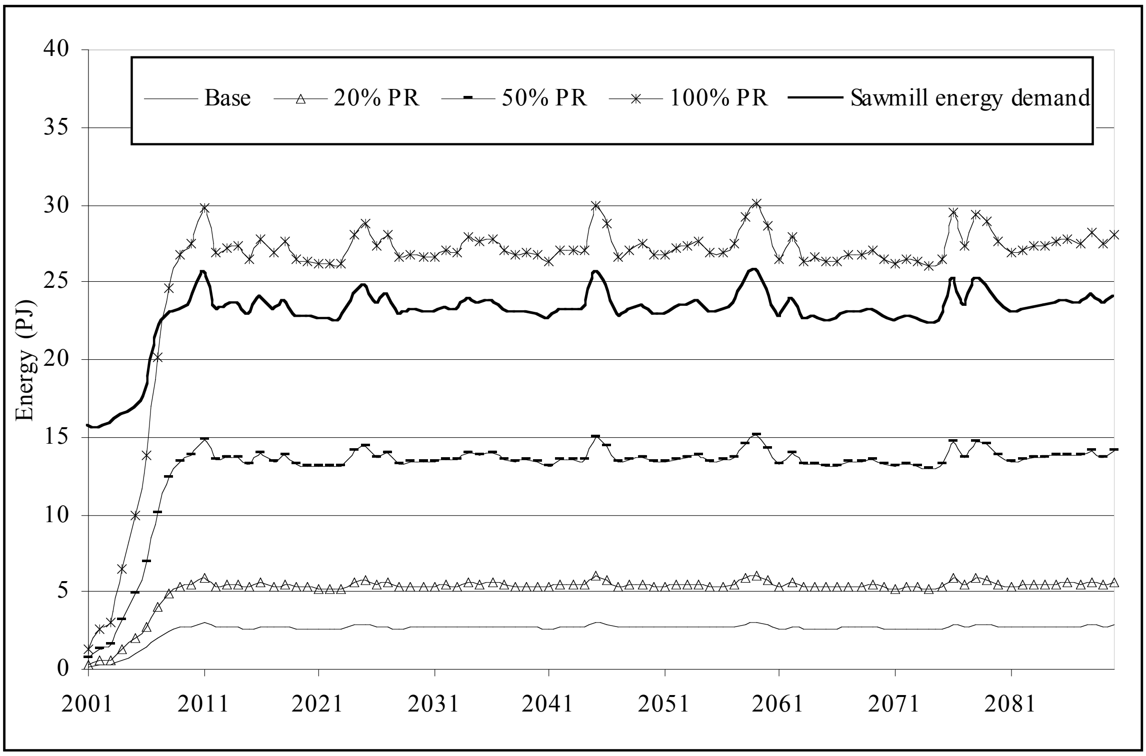

Figure 32. Sawmill energy demand and bioenergy potential from different proportions of processing residues used for bioenergy.

East Harbour Management Services (2002) assessed woody biomass resources in New Zealand and estimated processing residues available and its energy value. Their results are consistent with the estimates in this study.

It has been estimated by EECA (2001a) that the wood processing industry could double its use of biomass for the production of useable energy within the next five years. However, there is a range of significant barriers preventing more active deployment of bioenergy into the New Zealand market.

3.3 Barriers

Energy production from fossil fuels is one of the most important non-technical challenges which can limit the wider use of biomass energy systems (Rosch and Kaltschmitt 1999). Despite the unfavourable economic situation, there have been feasibility studies and biomass plants constructed over the last few years at locations with especially favourable conditions (e.g., in the wood processing industry). Rosch and Kaltschmitt (1999) analysed the following reasons for such failures: difficulties with funding, financing and insuring; unfavourable administrative conditions; organisational difficulties; lack of knowledge and adequate flow of information; and insufficient perception and acceptance. Wider use of biomass faces financial, administrative, organisational and infrastructural challenges, both real and perceived.

Several barriers to bioenergy uptake in New Zealand have been identified by EECA (2001a). These possible barriers are economic, technical, environmental and perception, and sociological barriers. They are discussed below along with brief opportunities.

Economic Barriers

The economic barriers are mainly related to cost of the biomass, capital cost, investment and transaction cost, and maintenance cost. The most significant barrier is the relatively high cost compared to conventional fossil fuel projects. Bioenergy plants have a higher capital cost compared to gas plants with longer payback periods, and investment costs are too high for many small industrial investors in bioenergy, such as sawmillers. Additionally, investors perceive the risks of bioenergy projects to be significant enough to invest in conventional fossil fuel energy projects. Economic risks of the energy market are also high due to competitive costs from fossil fuels, hydro and other renewables (e.g. geothermal and wind). Many industrial plant owners have a limited knowledge of investment in energy plant. As a result, they often purchase, modify and install second hand coal boilers which are often inefficient, require high labour input for de-ashing, and involve costly maintenance.

Technical Barriers

Lack of certainty of fuel supply at low cost is probably the second greatest barrier to achieving an increased uptake of bioenergy. Fuel supply risk from competing markets for biomass (e.g. fibre boards and bark mulch), varying quality of raw biomass as delivered to the plant, and long term supply requirements, all require appropriate contracts and forward sales agreements. Most woody biomass fuel suppliers are unused to long term contracts.

Biomass fuels are bulky and they often have high moisture content. Fuel standardisation is needed and guidelines need to be developed and risks from fuel variability reduced by developing techniques to cope with a range of fuel quality. Fuel handling and processing is often the most difficult component of an energy plant to adequately maintain and operate. Lack of available information and uncertainties of what are seen to be “new technologies” creates a problem. Time spent by management in learning about bioenergy options is scarce, and commitment is often lacking since energy inputs into a business are a small percentage of the bottom line and thus insignificant.

Environmental and Perception Barriers

Biomass has a negative image. It can have a poor image particularly when used in out-of-date appliances, viewed as a “fuel of the past” because of its historically low efficiency and high atmospheric emissions. Many low performing conversion technologies are already in place and operating.

There is a lack of good information available to potential bioenergy plant investors. Many rely on their own knowledge and will not, or cannot pay for quality advice. Sources of information are often derived from magazines or out-dated ‘public service’ published reports. Investors tend to have a strong view on what they want. Only a few have good information about their own processing plant and its energy requirements. The wood processing industry is only now becoming more technically aware and in the past many bioenergy developers have had unsuitable plant sold to them by unscrupulous or poorly informed equipment suppliers. There is a need to research and publish sound information on bioenergy to assist potential investors make appropriate equipment selection.

The energy balance of bioenergy is not always considered to be favourable. This is more the case for transporting biofuels produced from annual energy crops than for woody biomass from perennial crops where the energy output is at least ten to 20 times greater than the energy input. The collection and transport of biomass would result in increased use of vehicles, exhaust air emissions, and higher use of the roading infrastructure.

Sociological Barriers

There may be a future shortage of skilled forest workers for harvesting and collecting biomass as is already being experienced by the forest industry. So although employment opportunities from greater bioenergy uptake are often quoted, finding willing workers for potentially arduous work may not be easy.

While deregulation has made it easier for renewable energy projects to enter the electricity market, the low wholesale electricity price makes it difficult for renewable projects to compete in the wholesale market. Regarding maintenance cost, they could invest in new high quality, low labour intensity plant. A fuel supply merchant could be contracted to transfer the risk and give incentives to the supplier/growers to provide consistent fuel supplies.

Techniques for biomass fuel upgrading by natural drying, pelletising, briquetting etc are advancing. The quantity and characteristics of wood residues from forests or industrial sources varies over time. While a conversion plant may be designed for a specific fuel, over time it is highly likely that the mix of fuel available and its characteristics will change. This affects the design of the boiler and can shorten its economic life.

Development of guidelines and design protocols would assist operators. Physical handling of biomass fuels can be challenging to equipment designers and it has led to the failure of demonstration projects overseas particularly for bagasse. This could be addressed by the preparation of appropriate guideline manuals for establishing and operating biomass combustion plants.

3.4 Conclusions

- Bioenergy is not as attractive as using biomass for long lived products in terms of the carbon balance. It is the temporal profile of emissions that affect the balance results (i.e. instant emissions occur when biomass is used for bioenergy and emissions are delayed when biomass is used for long live products).
- Accounting. The carbon accounting methodology, the boundaries, the allocation of emissions and temporal profile affect the carbon balance. Using a conservative accounting approach for export logs, allocating responsibilities to the producer country and assuming instant emissions, leads to a positive relative balance if processing occurs on shore. Some emissions such as harvested wood product and residue emissions are delayed, and hence better balance for the whole industry is the result. These issues should be taking into consideration for international policy negotiations regarding HWP accounting.

- When higher proportion of processing residues are used for bioenergy there is: (i) a lower short term carbon balance (tC/yr) but equal balance for the long term (i.e same amount of emissions and different temporal profile); (ii) better carbon balance when emissions avoided are accounted for. The greater benefit for using bioenergy derives from the potential to improve the carbon balance by substituting and/or reducing additional emissions from fossil fuel sources.
- The sawmilling processing sector has the potential to produce more than enough energy from their residues than their needs. However, there are barriers to overcome in order to increase bioenergy use.
- The main barriers identified to bioenergy uptake are costs, image and knowledge about technology, handling, workers, etc. Lack of knowledge can be overcome by increasing the promotion of its use and benefits, in order to give signals to all sectors and enhance capabilities along the entire bioenergy chain .

CHAPTER 4. Land Use Economics

4.1 Introduction

The land use economic model was developed to assess whether forestry projects would need incentives to occur. The approach followed was to compare the land expectation value for the most common radiata pine regime in New Zealand, with the land market value (LMV) of sheep and beef farm land. The land expectation value (LEV) is the willingness to pay for bare land. It therefore, represents the maximum price a forest investor would pay for land before making the decision to establish new plantations. Based on the assumption that forest enterprises are purely based on economic decisions, if the land market value is higher than the land expectation value, additional revenues in the order of the difference between LMV and LEV will make the new planting option economically viable. Following this approach it was determined whether additional revenues are necessary to incentivise new planting, and the level of these was estimated.

4.2 Methodology

In this section the steps followed to estimate the land expectation value (LEV) for the radiata pine intensive tending without production thinning regime for the ten wood supply regions in New Zealand (Appendix III and Appendix IV) is explained. Different land market values at 2001-2002 for beef and sheep farming land use, within these regions, were compared to estimated LEV and the differences were assessed. An analysis of the breakeven carbon unit values, using the relationship developed in section 2.4.3, for the land market values recorded in 2001-2002 in each region and land type was performed.

4.2.1 Land Expectation Value

In order to compare the economic performance of alternative forestry projects, different indicators can be used. Examples of these include the net present value (NPV), and land expectation value (LEV).

The NPV is calculated by summing up the present value of expected revenues of the project and subtracting the sum of the present value of costs, which is expressed by the following formula:

$$NPV = \sum_{y=0}^{n} \frac{R_y}{(1+i)^y} - \sum_{y=0}^{n} \frac{C_y}{(1+i)^y} \qquad \text{[Eq] 11}$$

where R_y and C_y are revenues and costs at age y, respectively, and i is the discount rate.

A positive NPV indicates that the expected rate of return of the project is higher than the discount rate.

The NPV of an infinite series of future harvests at regular intervals with land initially bare is referred to as LEV, which can be regarded as the willingness to pay for the land. This indicator can be used for comparing projects, when the land is assumed to be used for growing timber in perpetuity and each successive crop involves identical values and costs. It is calculated over a perpetual series of timber crops, under the following assumptions: (i) all costs of growing trees are included apart from land costs; (ii) the interest rate reflects the context and outlook of the landowner; and (iii) the tending regime of the stand is the same in each future rotation (Davis *et al.* 1987). Mathematically the LEV can be calculated from the NPV for the first rotation as follows:

$$LEV = NPV * \frac{(1+i)^n}{(1+i)^n - 1} \qquad \text{[Eq] 12}$$

where n is the rotation length in years and i the discount rate. NPV in this case does not include the cost of the land or its opportunity cost. The discount rate used in this analysis was 8%.

The NEFD yield tables (MAF 2002) for one radiata pine croptype at 30 years harvest rotation age (Table 20) were used to estimate LEV at a wood supply region level. Revenues from harvested log types (i.e pruned logs, unpruned logs and pulp logs) and costs are the same as those used in Chapter 2 and are presented in Table 21 and Table 22 respectively. Overhead costs of $50/year were also included to cover all maintenance costs.

Table 19. Characteristics of the croptype used in the analysis

Initial stems/ha	Age (yrs)	Pruning height	Stems/ha after thinning
1200	6	2.2 m	400
	8	4 m	
	9	6 m	250

Table 20. Silvicultural costs for the selected regime.

	Silvicultural costs NZ$			
Age	**Planting costs**	**Tree releasing**	**Pruning**	**Thinning**
1	1100			
2		240		
6			700	400
8			650	
9			600	350

Note: regimes is radiata pine intensively tended without production thinning.

Table 21. Log type prices ($\$/m^3$) assumed for revenue estimates.

Species	Log type		
	Pruned	**Unpruned**	**Pulp**
Radiata pine	146.6	71.4	40.3

Transport costs are dependent on distance from forest to the destination site, such as processing plants, ports, etc. Transport costs ($\$/m^3$) were estimated as $4 plus $0.11/km times distance in km.

In order to assess the sensitivity of LEV to transport costs the economic analysis was performed for a range of transport distances (i.e 50, 100, 150 and 200 km) from forest. Harvesting cost was assumed to be $\$18/ m^3$ but a value of $\$25/m^3$ was also used to assess the effect on LEV.

4.2.2 Land Expectation Value vs. Land Market Value Analysis

The LEV for radiata pine at 30 years rotation age was compared to the land market value database from Meat and Wool Industry Economic Service. When LEV was higher than land market value it implies that would be economically viable to convert the land into forestry. However, when the LEV is lower than the market value, the forestry project does not achieve the 8% returns expected,. The required incentive value to make these values identical was estimated as the difference between LMV and LEV (i.e LMV-LEV).

The information on sheep and beef farm land market value for Hill, Hard Hill, Finishing Breeding by wood supply region was based on Speirs (2004) data at 2001-2002. Auckland and Central North Island wood supply regions are grouped in this classification. North Island Hard Hill country is steep hill country or low fertility soils mostly carrying between 6 and 10 stock units per hectare; North Island Hill country is easier hill country or higher fertility soils, mostly carrying between 8 and 12 stock units per hectare; South island Hill country is mainly mid micron wool sheep mostly carrying between 2 and 7 stock units per hectare; South Island finishing-breeding farms is a more extensive type of finishing farm, also encompassing some irrigation units and frequently with some cash cropping, and carrying capacity ranges from 6 to 10 stock units per hectare on drylands and over 12 on irrigated units. These market values are presented in Table 22.

Table 22. Land market values for all wood supply regions at 2001-2002.

Wood supply region	Land market value ($/ha)		
	North Island	Hill	Finishing/breeding
Northland	3770	4889	-
Auckland/ Central North Island	2035	4562	-
Hawkes Bay	1627	3099	-
Southern North Island	1644	4303	-
East Cape	139	2414	-
Nelson/Marlborough	-	867	-
Canterbury	-	1204	4323
Otago/Southland	-	2310	3240
West Coast	-	-	-

Note: There was no values reported in that year for the West Coast and Finishing Breeding land type in Nelson Marlborough region.

This approach to indicate the level of incentives needed to convert land to forest has some limitations that should to be taken into account. The LMV being equal to LEV is a necessary but not sufficient condition to convert land into forestry. There are many land use decisions that are not economically rational.

4.2.3 Land Market Value Analysis and Carbon Unit Value

The same approach followed in Section 2.4.3 to estimate carbon unit value was followed in this section. Carbon value in $ per tonne of carbon was estimated for the scenarios where deforestation and new land planting occurred ('deforestation' and new planting scenarios, 2, 5, 6, and 7).

4.3 Results and Discussion

The estimates for LEV ($/hectare), the carbon unit values ($/tC) for the given LMV, and the minimum additional value needed for the LEV to attain the LMV are presented in the following sections. The results of each analysis are discussed.

4.3.1 Land Expectation Value

Land expectation values of *Pinus radiata* at 30 years rotation age, assuming 8% discount rate, for $18/ m^3 of harvesting cost, four transport distances and for the 10 wood supply regions are illustrated in Figure 33 and Table 24. The Central North Island, Gisborne, Hawkes Bay and Southern North Island regions were the only regions that showed positive LEV for some transport distances. In all cases these values were lower than $1000/hectare. Gisborne and Southern North Island were the regions that exhibited higher LEV and positive values even at transport distances of 150 km. The other six regions exhibited negative LEV at all transportation costs analysed.

The difference between regions was the result of different revenues and costs of transport and harvesting arising from the total recoverable volume produced at harvest rotation, given that silvicultural costs were identical for all of the regions to meet the objective that was to analyse transport and harvesting costs impact. These four regions with positive LEVs produced similar (and the highest) recoverable volumes (Figure 34).

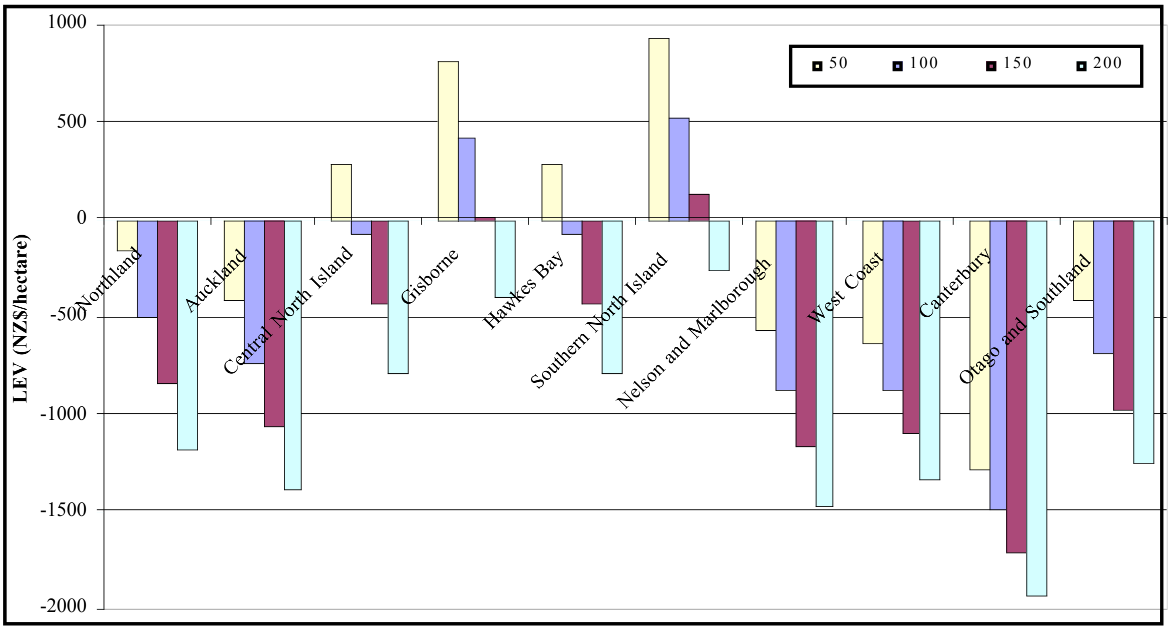

Figure 33. LEV ($/hectare) for each wood supply regions, different transport costs and 18 NZ/ m^3 of harvesting costs

Table 23. LEV ($/m^3$) for each wood supply regions, different transport distances and $18/ m^3 of harvesting costs

	LEV (18 NZ$/m3 harvesting cost)			
	50	100	150	200
Northland	-151	-492	-833	-1174
Auckland	-404	-730	-1056	-1382
Central North Island	294	-67	-428	-789
Gisborne	825	421	18	-386
Hawkes Bay	294	-66	-426	-786
Southern North Island	930	535	139	-257
Nelson and Marlborough	-572	-869	-1165	-1462
West Coast	-629	-862	-1096	-1330
Canterbury	-1277	-1491	-1705	-1919
Otago and Southland	-408	-690	-972	-1254

Although the Southern North Island region had lower total recoverable volume than the Gisborne (Figure 34), it showed higher LEVs. This was the result of a combination of higher revenues from a lower proportion of low value logs (i.e pulp logs) and lower total transport and harvesting cost that are directly related to TRV.

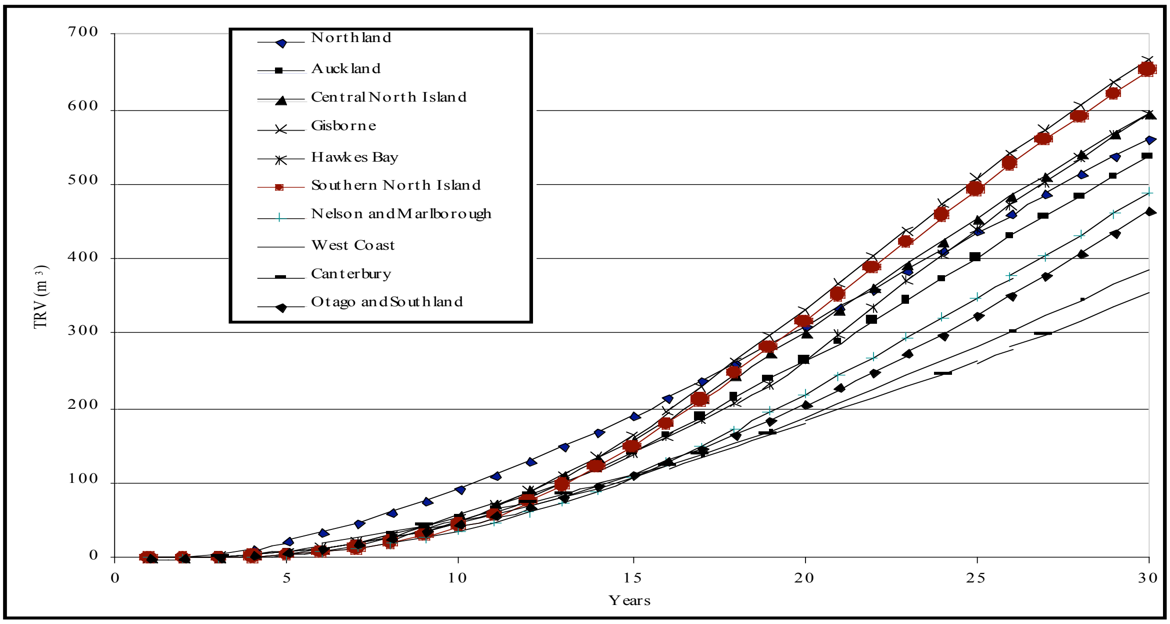

Figure 34. Total recoverable volume of the regime analysed, from age 1-30 and for each wood supply region.

The LEV was also estimated assuming higher harvesting costs that would apply to hauler systems (i.e \$25 / m^3) (Figure 35 and Table 25). Under this assumption only Gisborne and Southern North Island regions showed positive LEV, and for both regions the values were lower than \$500 /hectare.

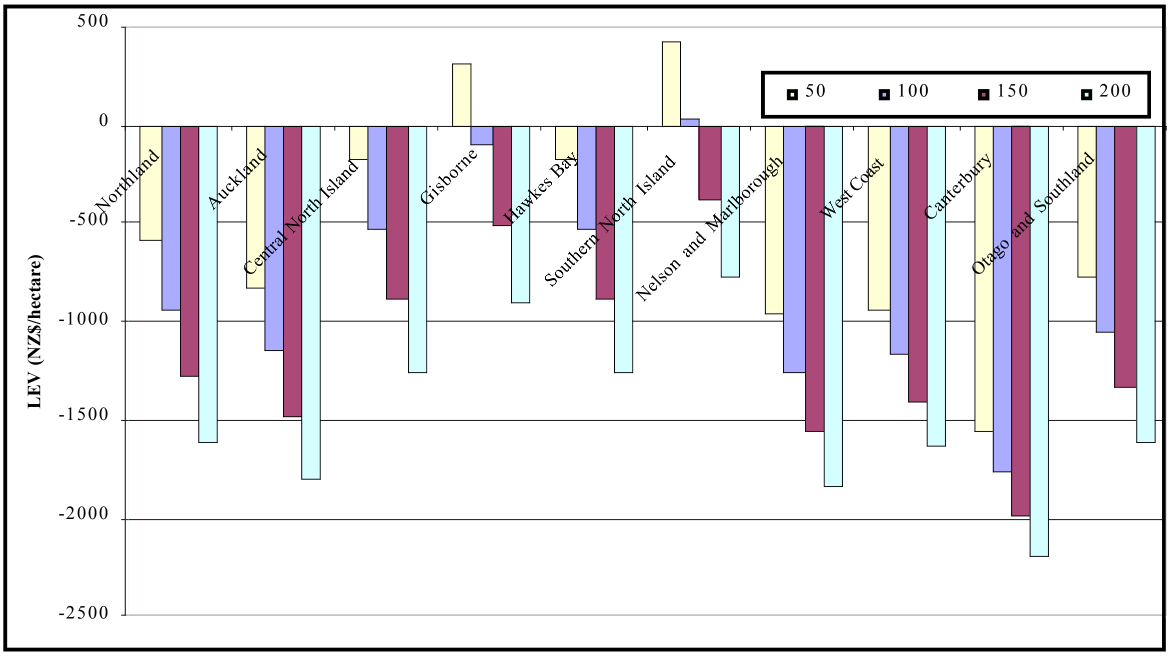

Figure 35. LEV (\$/hectare) for each wood supply regions, different transport costs and \$25/m^3 of harvesting costs.

Table 24. LEV ($/hectare) for each wood supply regions, different transport costs and 25 $/ m^3 of harvesting costs.

	LEV (25 NZ$/m3 harvesting cost)			
	50	100	150	200
Northland	-585	-926	-1267	-1608
Auckland	-819	-1145	-1471	-1797
Central North Island	-165	-526	-887	-1249
Gisborne	311	-92	-496	-899
Hawkes Bay	-164	-524	-884	-1244
Southern North Island	427	31	-365	-760
Nelson and Marlborough	-950	-1246	-1543	-1840
West Coast	-926	-1160	-1393	-1627
Canterbury	-1549	-1763	-1978	-2192
Otago and Southland	-767	-1049	-1331	-1613

4.3.2 Land Expectation Value vs. Land Market Value Analysis

The value at which LMV exceeds LEV indicates the level of additional revenues needed to convert the land into forestry attaining higher than 8% returns. The range of these values varied from approximately $580/ha for the Nelson and Marlborough regions on finishing/breeding land, to approximately $6500/ha for finishing/breeding land in the Canterbury region. These relative values estimated for all regions, for a range of transport distances (i.e 50, 100, 150 and 200 km) and two harvesting costs ($18 and $25/ m^3) are presented in Appendix II.

Based on the assumption for harvesting costs of $18/$m^3$ and a range of distances to destination site of 50, 100, 150 and 200 km and the lowest LMV for each region, the Southern North Island region showed the lowest relative values, followed by Hawkes Bay, Nelson-Marlborough, Central North Island, Auckland, Canterbury, Otago-Southland, Gisborne and Northland (Figure 36).

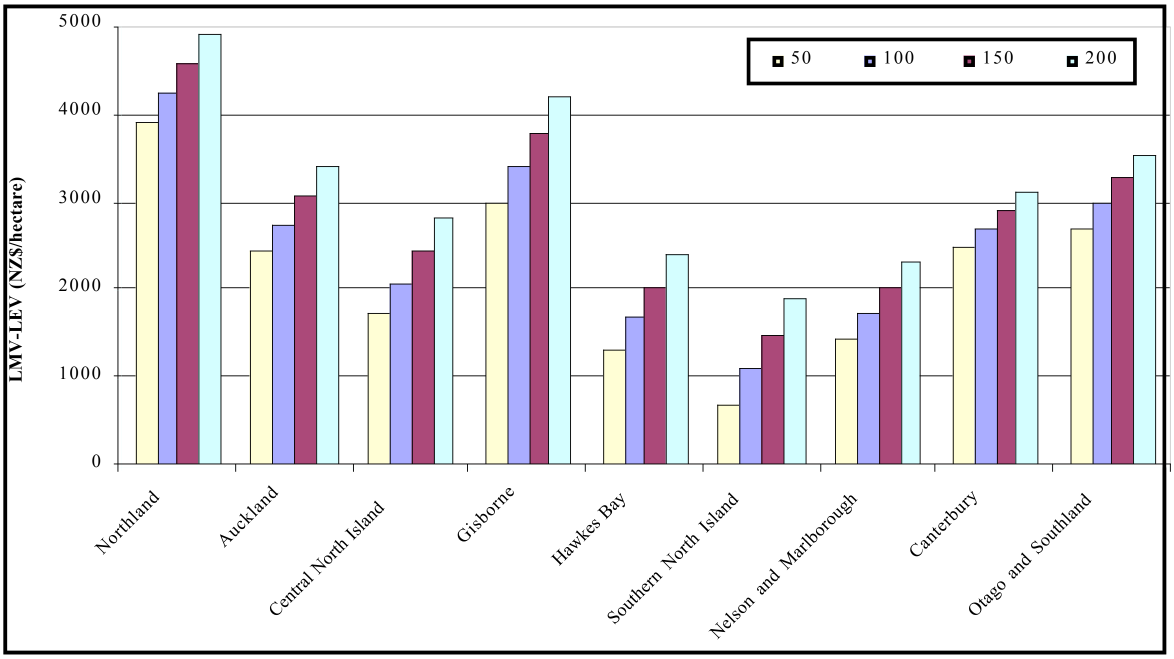

Figure 36. Relative LMV to LEV for all regions and Hard Hill and Hill land types for the North and South Island respectively.

4.3.3 Land Market Value and Carbon Unit Value

In order to provide information on the value of carbon as a possible incentive for new forest plantings or avoidance of deforestation, the per unit carbon value at the land market values (i.e. land cost or land revenue) for scenarios 2, 5, 6, and 7 that include new planting (Table 25) was estimated.

The range of carbon unit values ($/tC NAE) for high value land (i.e Hill land for the North Island and Finishing Breeding for the South Island) are illustrated in Figure 37. Figure 38 illustrates the carbon unit values for the low value land (i.e Hard Hill for the North Island and Hill for the South Island).

Table 25. Carbon unit values ($/tC NAE) necessary to make new planting or avoiding deforestation profitable under different land market values.

			Scenarios			
Land type	Region	Land market value	5(New pl 20)	6(New pl 60)	7(New pl 60 hardw)	2(Deforestation)
Hill/Finishing Breeding	Northland	4889.4	70.4	70.2	53.9	66.4
	Auckland	4562.3	65.9	65.7	51.2	62.0
	Central North Island	4562.3	65.9	65.7	51.2	62.0
	Gisborne	2414.3	36.3	36.5	33.2	33.7
	Hawkes Bay	3098.9	45.7	45.8	38.9	42.7
	Southern North Island	4303.5	62.3	62.2	49.0	58.6
	Canterbury	4322.8	62.6	62.4	49.2	58.9
	Otago and Southland	3239.9	47.7	47.7	40.1	44.6
Hill/Hard Hill	Auckland	2034.9	31.1	31.3	30.0	28.6
	Central North Island	2034.9	31.1	31.3	30.0	28.6
	Gisborne	1392.4	22.3	22.6	24.7	20.1
	Hawkes Bay	1626.6	25.5	25.7	26.6	23.2
	Southern North Island	1643.9	25.7	26.0	26.8	23.5
	Nelson and Marlborough	866.8	15.0	15.4	20.3	13.2
	Canterbury	1203.9	19.7	20.0	23.1	17.7
	Otago and Southland	2310.3	34.9	35.1	32.3	32.3

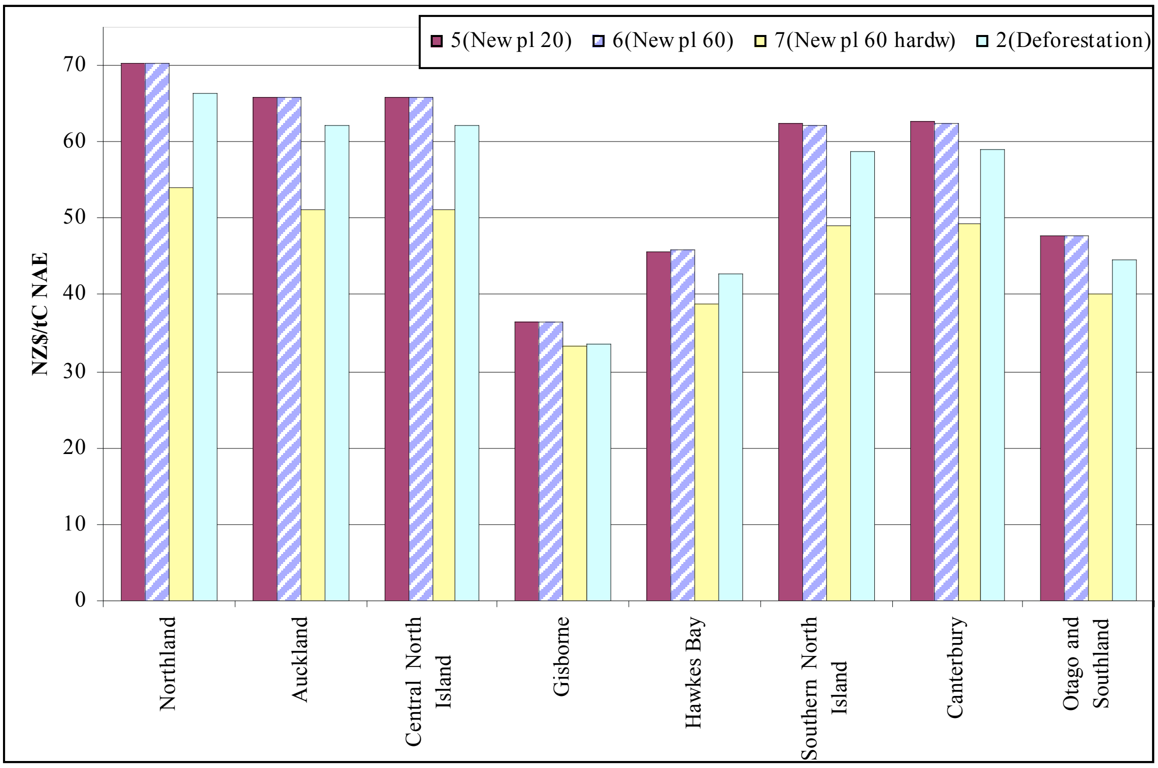

Figure 37. Levels of carbon unit values ($/tC NAE) necessary to make new planting or avoiding deforestation profitable by high value land in each region.

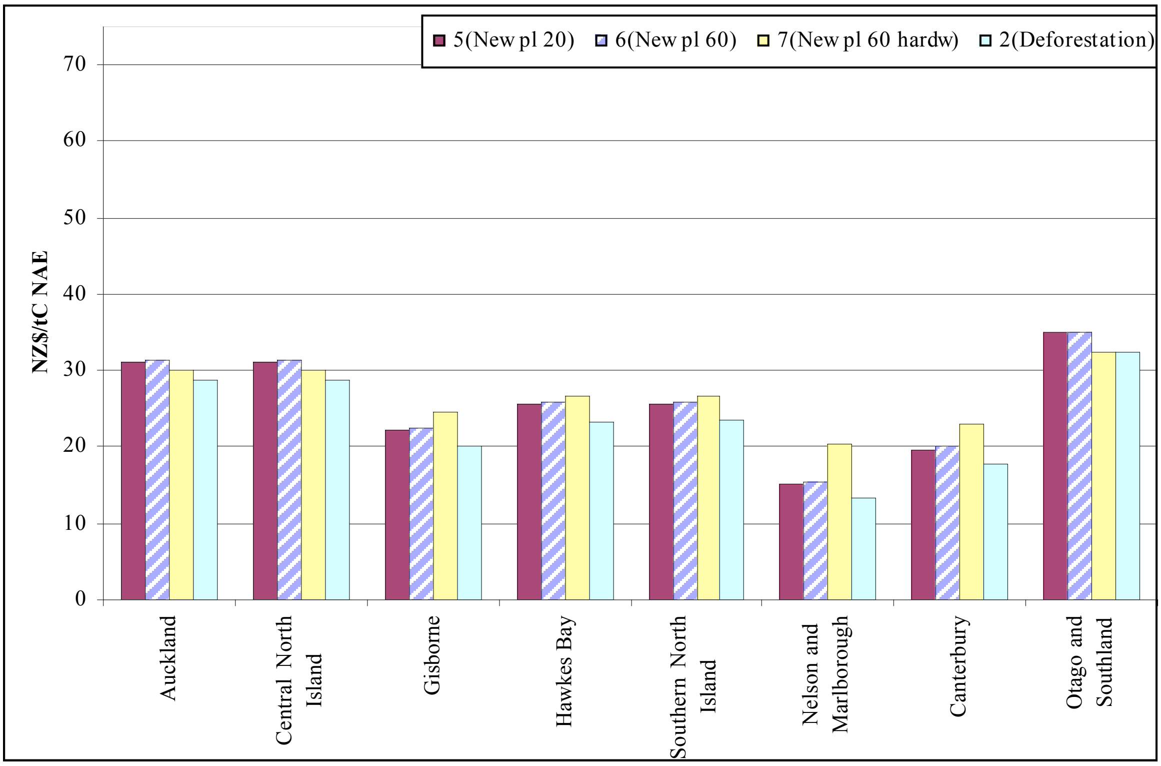

Figure 38. Levels of carbon unit values ($/tC NAE) necessary to make new planting or avoiding deforestation profitable by low value land in each region.

Under the assumptions made in this study it was found that each project would need to include an additional carbon value, to make new planting or retention of forest profitable (i.e returns higher than 8%). The value of carbon needed to make other scenarios more profitable varied depending on the planned type of forest estate and the market value of land. The higher the land value, the higher the carbon price necessary to increase the returns of the land use change to above 8%. The lowest carbon unit value to make a change in the economics of mitigation options through land use management was 13.2 $/tC. At this carbon unit value, the retention of forest rather than deforestation of land on Nelson Marlborough sold at almost $900 /ha, would become profitable. In order to encourage new planting on the same region (i.e scenarios 5, 6 and 7, respectively) and the same land type, at least 15, 15.4 and 20.3 $/tC were needed in additional revenues.

4.4 Conclusions

- LEV is negative except for low transport distances and only in Gisborne, Southern North Island, Central North Island and Hawkes Bay. The whole South Island had negative LEV. This is consistent with the national forest estate level analysis in which new planting showed negative NPV. Therefore, incentives to improve the profitability of new plantings are needed.

- The LMV was higher than LEV; thus additional revenues are needed to make conversion of land to forestry economically viable.
- The lowest level of incentives that would be needed (i.e values that equal LMV and LEV) based on the assumption of 50 km distance to destination site and 18$/ m^3 for harvesting costs, was 580 $/ha. The highest value recorded under the same assumption was 5600 $/ha.
- Given the market value of land recorded, the lowest carbon unit value to make a change on the economics of mitigation options through land use management (i.e avoiding deforestation) was 13.2 $/tC. The highest carbon unit value recorded was 70.4 $/tC.

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CHAPTER 5. Carbon Benefits and Discounting

The forest and forest industry produce goods with market values such as wood products, as well as environmental services such as carbon sequestration. It has been discussed that the industry as a whole also has an effect on the carbon balance with the atmosphere through carbon emissions from plantations, the processing sector, and wood products and residues. Forest enterprises are mainly driven by the market rate of return to investments. These investments affect the net atmospheric exchange of carbon to the atmosphere, and emissions at a global level that may also have a market value such as through the Kyoto Protocol mechanisms. However, implicit in these effects there is a non market value for society in general, which might value these benefits and disbenefits at the same discount rate or not.

A number of methodological aspects of the economics of carbon sequestration are still a matter of debate and thus require further research. These methodological aspects include the definition of appropriate discount rates when carbon is considered as an environmental benefit from forests.

One of the objectives of this study was to investigate the use of discount rate on the economic analysis of carbon benefits as one of the environmental values of forest. This issue is addressed in this chapter. The first section discusses the implications of cost benefit analysis and the theory of discounting as related to the economics of climate change and carbon benefits. Afterwards, the implications of discount rates on the net atmospheric exchange (NAE) and carbon balance of the national level scenarios estimated in Chapter 2 are reconsidered.

5.1 Introduction.

An important application of discounting the distant future is valuation of the consequences of climate change due to human activities, such as burning of fossil fuels and emission of carbon dioxide that remain in the atmosphere for hundreds of years (Newell and Pizer 2003), as well as analysing environmental projects or activities with long term effects (Weitzman 1998).

A critical feature of the distant future is the currently unresolvable uncertainty about what will then be the appropriate rate of return on capital to use for discounting. Weitzman (1998) discusses how to discount distant future in a way as *"will induce us to make the best possible investment decisions now, in our present state of uncertainty about the relevant interest rate that will then apply"*.

With regard to actions taken to affect GHG balance such as climate change and forest policies, the effect must be considered in global terms and upon future generations. The other issue of concern is the uncertainty related to the effect of emissions of GHG.

The evaluation of environmental policies frequently requires balancing near-term mitigation costs against long-term environmental benefits. To make these costs and benefits comparable, conventional economic theory suggests discounting future consequences based on market rate of return to investment. In this way, one gains assurance that environmental policies provide benefits that are at least as good as other productive activities such as forest investment. Several practical issues complicate the application of this concept (Newell and Pizer 2004), and no consensus exists on the appropriate rate to use for discounting.

In the case of policies to mitigate climate change, the time horizons involve centuries for which there are no comparable market investments that establish future rates of return (Newell and Pizer 2004). Economic valuation can be controversial, and requires sophisticated analysis that is still mostly lacking in a climate change context (Tol 2005).

Nordhaus (1997) presents different approaches that have been proposed to design global warming policies, such as lower discount rate, differential discounting, climate targeting and emissions limitations.

Conventional discounting, decreasing discounting, certainty equivalent factor will be discussed further in this section.

Conventional discount rate

Conventional analyses, using constant rates, tend to produce low estimates of climate change damages and recommend moderate if not marginal mitigation action. Other analyses, based on lower discount rates, produce significantly higher climate damage estimates and recommend aggressive action (Newell and Pizer 2003).

Philibert (1999) discusses the present value of future climate change, arguing economic theory holds that a single unified discount rate is a necessary condition for the efficient allocation of resources in a global economy. Therefore, it is not really advisable to use a specific rate for analysis of climate change. By way of example he explains that if a standard discount rate (between 5 and 10%) is used, the economic analysis will assign a very low present cost to eventual future damages, even discounting at 8% over 100 years comes down to dividing by 2200, and will in conclusion legitimatise inaction (Philibert 1999).

There have been various proposals to resolve this issue by using "normal" discount rates for the near future and "low" discount rates for the distant future. The proposed mechanisms range from openly ad-hoc adjustments to formal axiomatic treatments (Weitzman 1998).

Weitzman (1998) shows that there is a clear sense in which the lowest possible interest rate should be used for discounting the far-distant future of any investment project. Newell and Pizer (2003) demonstrate that when the future path of the discount rate is uncertain and highly correlated, the distant future should be discounted at significantly lower rates than suggested by the current rate.

Philibert (1999) explains that arguments in favour of low rates generally pursue the following line of reasoning: (i) demonstrate the domination of the social rate of preference for the present, over the marginal rate of return on private investment; (ii) demonstrate that individuals are isolated by markets, and cannot express their real preferences with respect to future generations.

Newell and Pizer (2003) also notes that some economists have argued that applying a positive rate of pure time preference to discount values across generations is *''ethically indefensible.''* Policymakers have already, in some cases, begun to apply lower discount rates to long-term, intergenerational projects.

On the other hand, Philibert (1999) claims that low discount rates would imply more sacrifices for present generations, although future generations may be richer, and using multiple rates would lead to economic inefficiencies. If the discount rate is lowered, it is the equivalent of saying that the present generation must invest much more and hence, consume less and save more to benefit descendants presumably richer than we are. He also stresses that these conclusions are contrary to common sense and shows that arguments favouring a low or zero discount rate in general are weak, even from an ethical point of view. Newell and Pizer (2003) also supports his argument explaining that the approach of applying lower discount rates to long term intergenerational projects comes close to causing the same time-consistency problems as long term projects in the present become near-term projects in the future.

Another possible approach proposed has been to apply declining discount rates.

Declining discount rate

Philibert (1999) considers different arguments in favour of discount rates decreasing over time, based on the argument that non-reproducible environmental assets should be given a value growing over time. He shows that this argument implies that the costs of damages associated to climate change should not be underestimated, and reinforces the legitimacy of using decreasing discount rates. Arguments in favour of a rate declining over time, and in favour of increasing valuation of natural assets are based on a declining discount rate being the necessary outcome to the slowing down of economic growth. The main arguments are: (i) a spread between the discount rate and the pace of economic growth raises insoluble problems in the long run; and (ii) the absolute rarity of certain natural assets warrants that their relative value rise progressively.

A set of arguments has been developed in favour of rates falling ultimately to a low value. Declining discount rate and growing valuation of environmental assets are not independent.

Newell and Pizer (2003) also discussed the use of a declining rate of discount, which is referred to as hyperbolic discounting. They affirm that the use of a declining rate, consistent with individual preferences, produces time-inconsistent decisions. Weitzman (1998) argue that climate change is too uncertain to say anything about the marginal damage costs of carbon dioxide emissions. Newell and Pizer (2003) endorses that uncertainties are indeed substantial, and discounting over long horizons requires considering the uncertainty surrounding future discount rates.

Uncertainty

Weitzman (1998) concludes that uncertainty about future discount rates provides a strong generic rationale for using certainty-equivalent social discount rates that decline over time, from around today's best average estimate based on market values, down to the smallest rates for the far distant future.

Newell and Pizer (2003) makes the distinction with most applications of geometric discounting acknowledge that the discount rate itself is uncertain. As a direct consequence, there is an increase in the expected net present value of future payoffs. Because discounted values are a convex function of the discount rate, the expected discounted value will be greater than the discounted value computed using an average rate. The variable over which expectations should be taken is not the discount rate (r), as is typically done, but rather the discount factor (e^{-rt}).

Newell and Pizer (2004) explains that although the dollar value of discounted climate benefits is sensitive to the magnitude of the benefits, the proportional increase due to uncertainty depends only on the general shape of the profile. The author has considered the effect of uncertain future discount rates on the valuation of future benefits, distinct from any uncertainty about the magnitude of the benefits themselves. This implies that the valuation of benefits occurring in the future is less sensitive to the choice of the current discount rate when the effect of uncertainty is taken into account.

Newell and Pizer (2003) computes the ''certainty-equivalent rate'' that summarizes the effect of uncertainty and measures the appropriate forward rate of discount in the future. Implicit in any long-term cost-benefit analysis is the idea that costs and benefits can be compared across long periods of time using appropriate discount rates.

Newell and Pizer (2003) assesses two uncertainty models: random walk model and mean reverting model. The effect of discount rate uncertainty based on the random walk model increases the estimated benefits of mitigation by over 80% using the benchmark 4% rate, 95% increase in discounted mitigation benefits relative to constant discounting with a 7%

rate and a 56% increase with a 2% rate. The mean-reverting model yields a more modest increase of only 14% using 4% discount rate, 21% increase using the 7% rate, and a 7% increase using the 2% rate. The relative effect of uncertainty on the present value of expected mitigation benefits is larger when the comparison involves a higher initial discount rate.

Although the average long-term real rate of return on government bonds is around 4%, the appropriate rate to discount the distant future (more than 400 years) is around 0.5% based on a random walk model, and 1% based on a mean-reverting model. Over horizons of less than 400 years, the random walk model suggests declines to much lower rates: 2% after 100 years, 1% after 200 years, and 0.5% after 300 years. Certainty-equivalent rates for the mean-reverting model, on the other hand, remain above 3% for next 200 years, declining to 2% only after 300 years and 1% after 400 years. At a practical level, the random walk model generates prediction intervals with better coverage in split samples than the mean-reverting model.

In general, the greater the proportion of benefit occurring in the distant future, the greater the error introduced through discounting that ignores uncertainty in the discount rate itself. These results indicate that the expected marginal benefits from climate change mitigation could be understated by a factor of 2 in analyses that ignore uncertainty in the discount rate itself (Newell and Pizer 2003).

Weitzman (1998) suggests that the decline in certainty-equivalent social discount rates might be sufficient to warrant checking out this possibility for any cost-benefit analyses of long-term environmental projects, like mitigating the effects of global warming. For long-term environmental evaluations the optimal choice of policy instruments and levels of imposed stringency may well be distorted toward what would be optimal for a low-interest-rate situation because, other things being equal, that situation will carry relatively more weight in determining the expected difference between present discounted benefits and costs.

In summary, not only do valuations rise when uncertainty is considered, but they become less sensitive to what the analysis is based on. Using conventional discounting techniques to value benefits over hundreds of years make future benefits insignificant, and to many people, that seems wrong. Newell and Pizer (2004) results shows that constant discount rates do in fact undervalue the benefits of GHG abatement measures. Moreover, they suggest that this concern is at least partially addressed by viewing future interest rates as uncertain. Although this will not yield the same dramatic effects as the decision to arbitrarily apply a lower discount rate, uncertainty does have a large effect on consequences valued at horizons of 70 years or more in the future (Newell and Pizer 2004).

5.2 Implications of Discounting on NAE and Balance

Different time-paths of net atmospheric exchange and balance are associated with each of the seven scenarios examined in section 2.5.2 and 2.5.3. All scenarios were then evaluated through estimates of present value of net atmospheric exchange and balance using a standard 8% market based discount rate. The discussion and conclusions drawn were based on and relied on the discount rate used. Because of the long time horizons employed in the analysis and its implications previously discussed, it is important to look at the sensitivity of the results to the assumed discount rate.

Several approaches have been proposed to address the issues of time-preference and discounting on climate change benefits. In this section, an analysis testing standard but arbitrary lower discount rates to (i) carbon net atmospheric exchange of forest plantations and (ii) carbon balance for the whole industry, was performed for all scenarios. The trend followed by each scenario at different discount rates is discussed. Subsequently, the break-even discount rate at which 'limit on harvesting' (3) and 'target rotation' (4) scenarios reach the same present value was estimated with the aim of discussing these implications.

Changing the discount rate had two types of effects on the simulations. First, all of the indicators took on new values. Second, the present value of NAE and balance relative to the base scenario was affected by changing discount rates, leading to different scenarios preferences.

In Figure 39 and Figure 40 the impact of changing discount rates on the present value of NAE and balance respectively is illustrated. When both patterns are examined, the relative order (ranking) of the various scenarios for the NAE was different to the ranking in carbon balance.

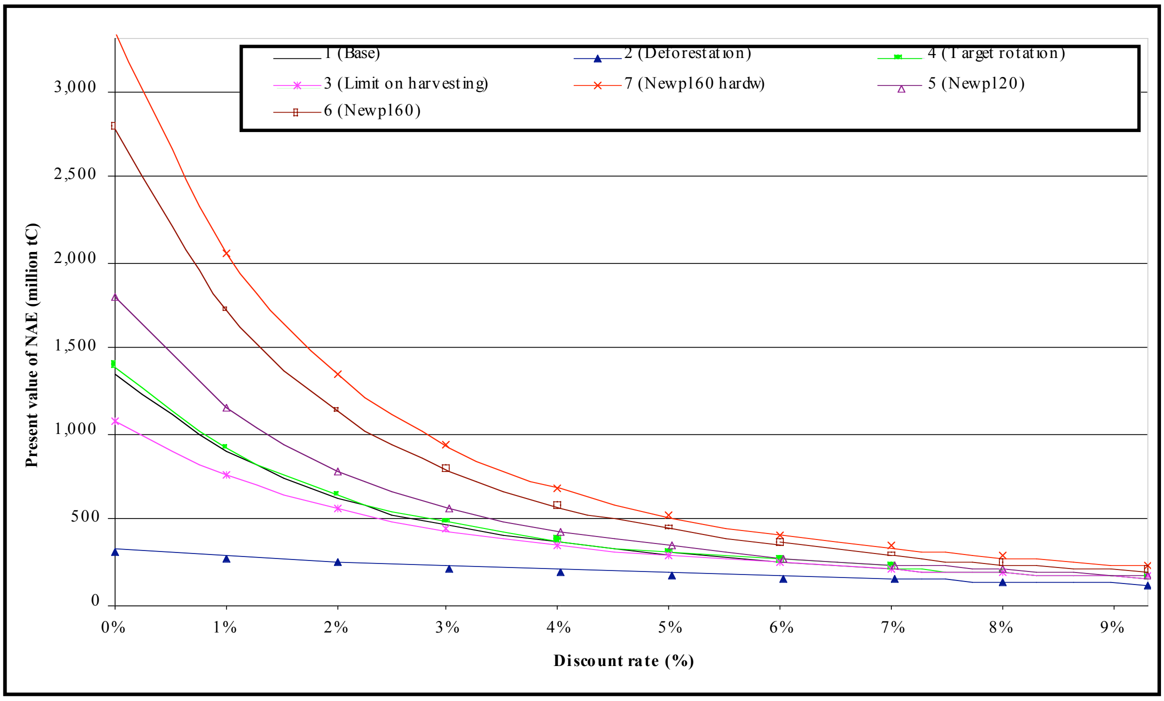

Figure 39. Present value of NAE (tC) for all scenarios at different discount rates.

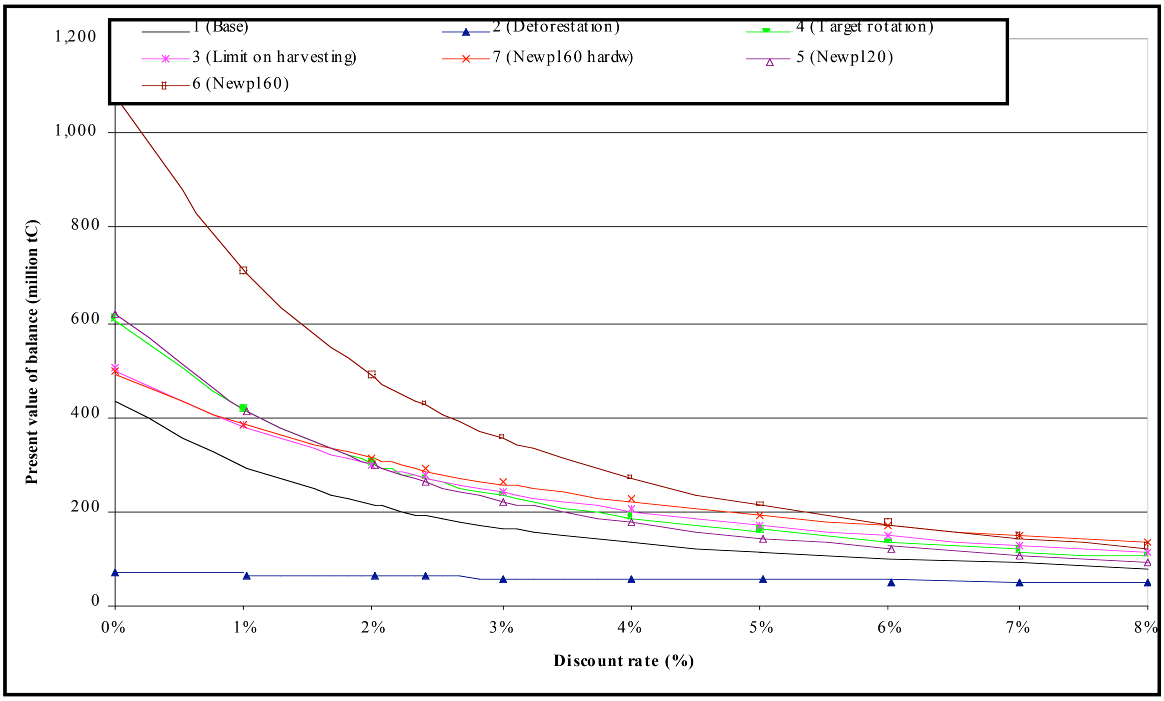

Figure 40. Present value of balance (tC) for all scenarios at different discount rates

Even though the NAE ranking of each scenario remained constant, the long term effect to the atmosphere became more apparent at discount rates below 8% as the NAE attained higher values (Figure 39).

The implications of the effect of changing the discount rate can also be evaluated by looking at the relative NAE and C balance for each scenario and the corresponding value estimated for the base scenario. These indicators are illustrated in Figure 41 and Figure 42. The relative NAE of new planting scenarios increased with lower discount rates. Even though "target rotation" (4) had a lower increment in terms of relative values than the other scenarios, it remained with positive relative values of relative NAE and carbon balance. 'Limit on harvesting' (3) and deforestation (2) showed decreasing and negative relative NAE to base when the discount rate decreased. At lower discount rates, the negative impact of changing the forest estate from the base scenario to deforestation or setting a constraint on harvesting was obvious.

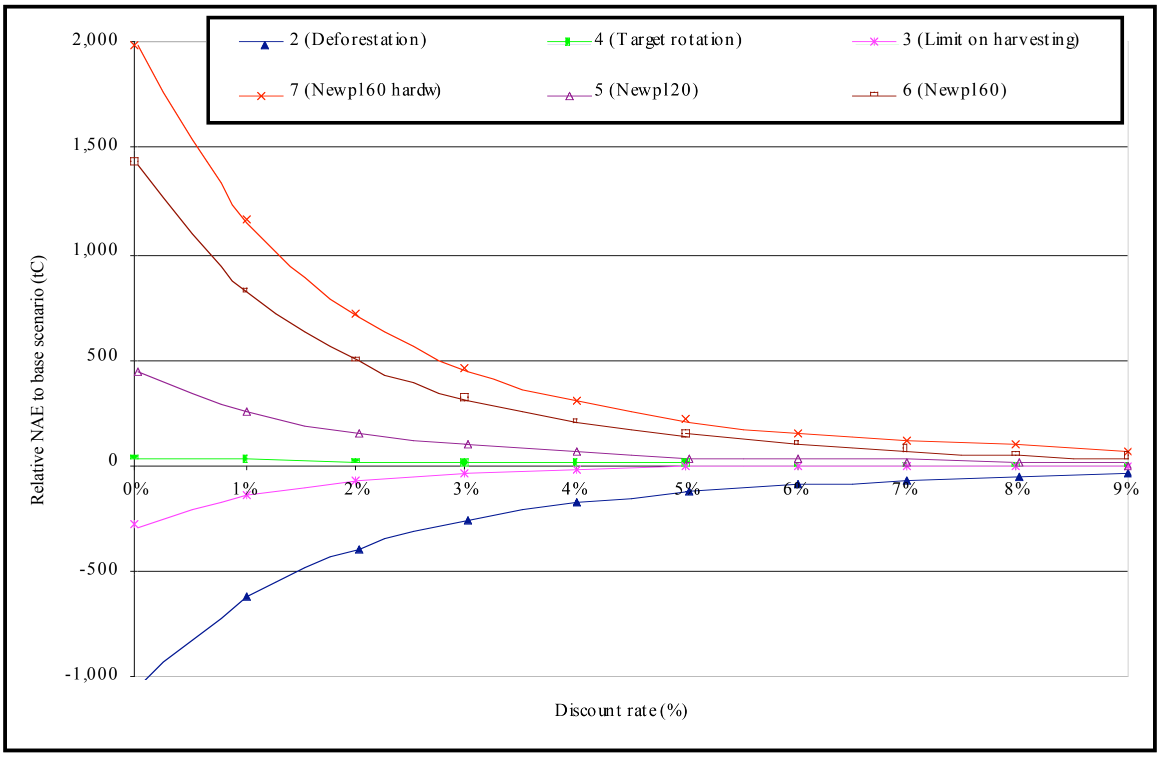

Figure 41. Relative NAE (tC) to base scenario for all scenarios under different discount rates

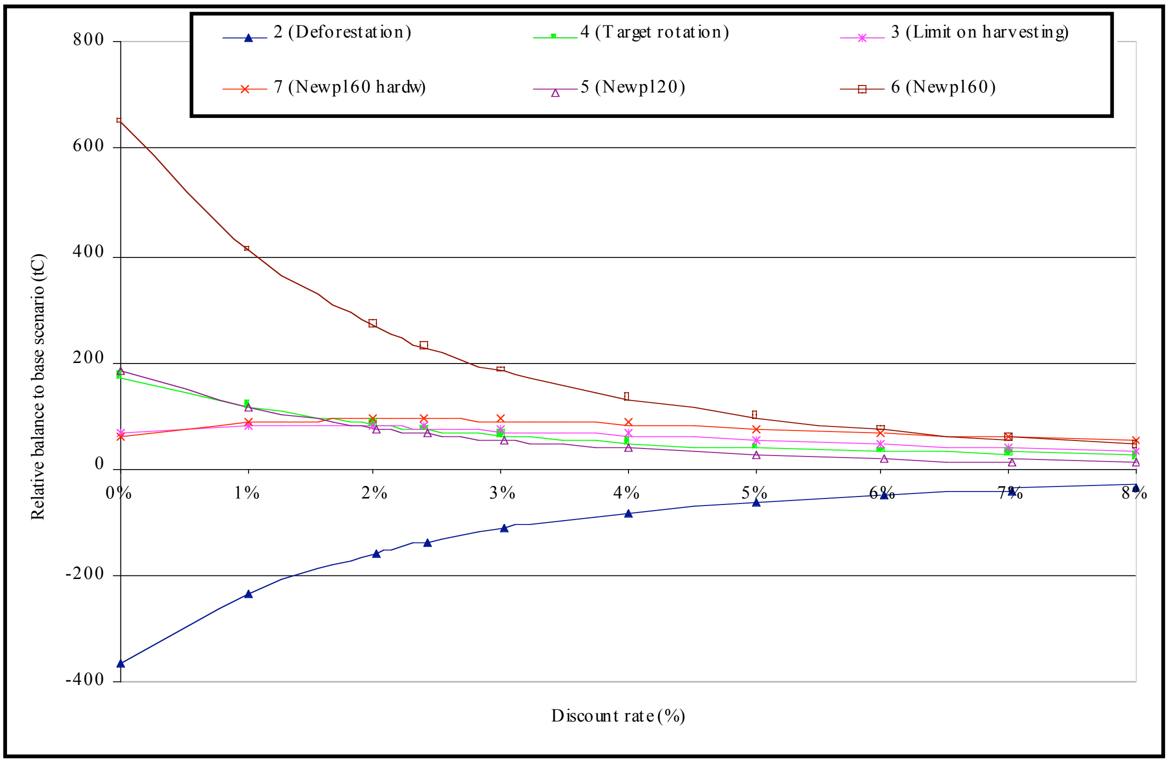

Figure 42. Relative balance (tC) to base scenario for all scenarios under different discount rates.

When the scenarios were analysed from the perspective of relative carbon balance from the whole industry, interactions between scenarios were observed. In scenarios with 60 and 20 thousand hectares of new planting with the same croptypes and ‘target rotation’ scenario (4), the relative balance increased with lower discount rates. In contrast, in ‘limit on harvesting’ (3) and 60 thousand hectares of hardwoods scenarios, the relative balance to base showed lower values at 0% discount rate.

As was observed in section 2.5.2 the present value of NAE for ‘target rotation’ (4) and ‘limit on harvesting’ (3) scenarios were similar at 8% discount rate. However, the relative carbon balance values for ‘limit on harvesting’ (3) decreased over time, implying that in the long term, there were decreasing benefits of this scenario to the atmosphere as compared to the base scenario. This effect was not noticeable at 8% discount rate, but it became evident at lower discount rates (Figure 43).

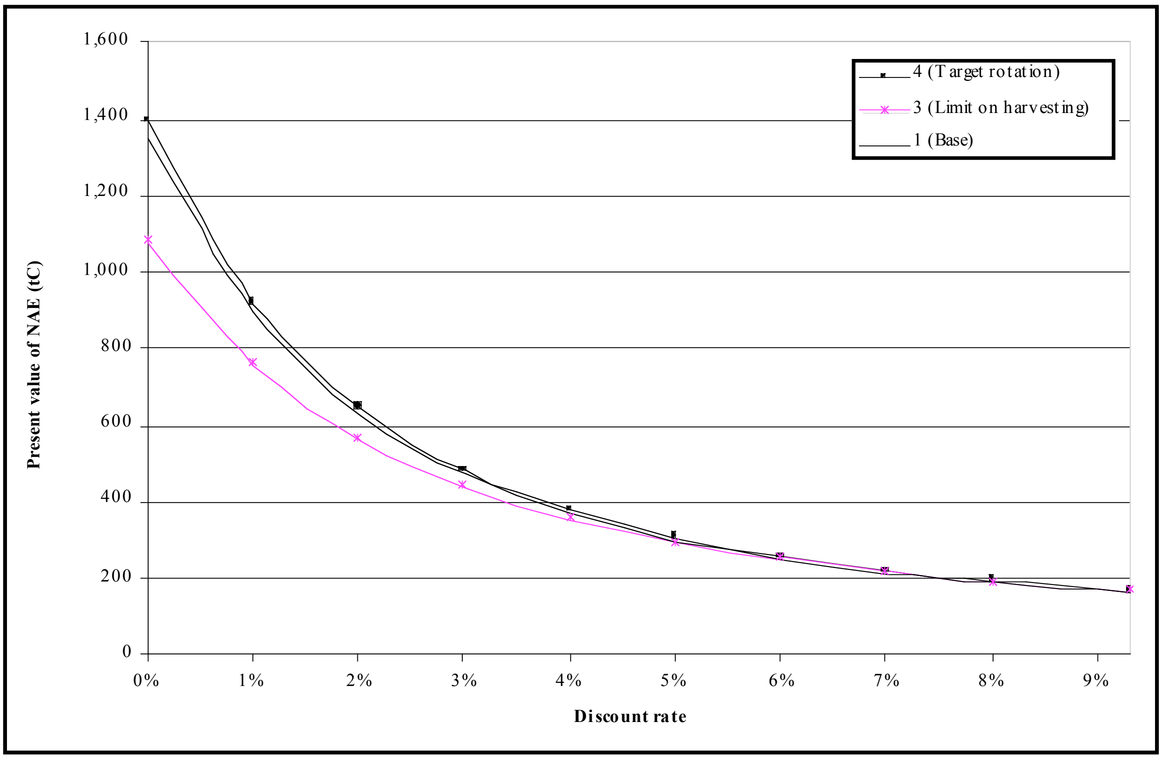

Figure 43. Present value of NAE for base scenario, ‘limit on harvesting’ (3) and ‘target rotation’ (4) at discount rates from 0% to 9.3%.

The discount rate at which both scenarios had the same present value of relative NAE to base (i.e break-even discount rate) was examined (Figure 43). It was found that the break-even discount rate was 9.3%. Below that discount rate, ‘limit on harvesting’ scenario (3) not only had lower relative values than the ‘target rotation’ (4) scenario, but it also attained negative values of relative NAE (Figure 44). The negative values of NAE relative to the baseline scenario imply that it would be better to remain with the base scenario than changing the national forest estate by imposing a limit on harvested volume in order to attain sustainable harvesting over time. In contrast, it would be beneficial to change the forest estate from the base scenario to longer harvesting age, if lower discount rates were to be considered.

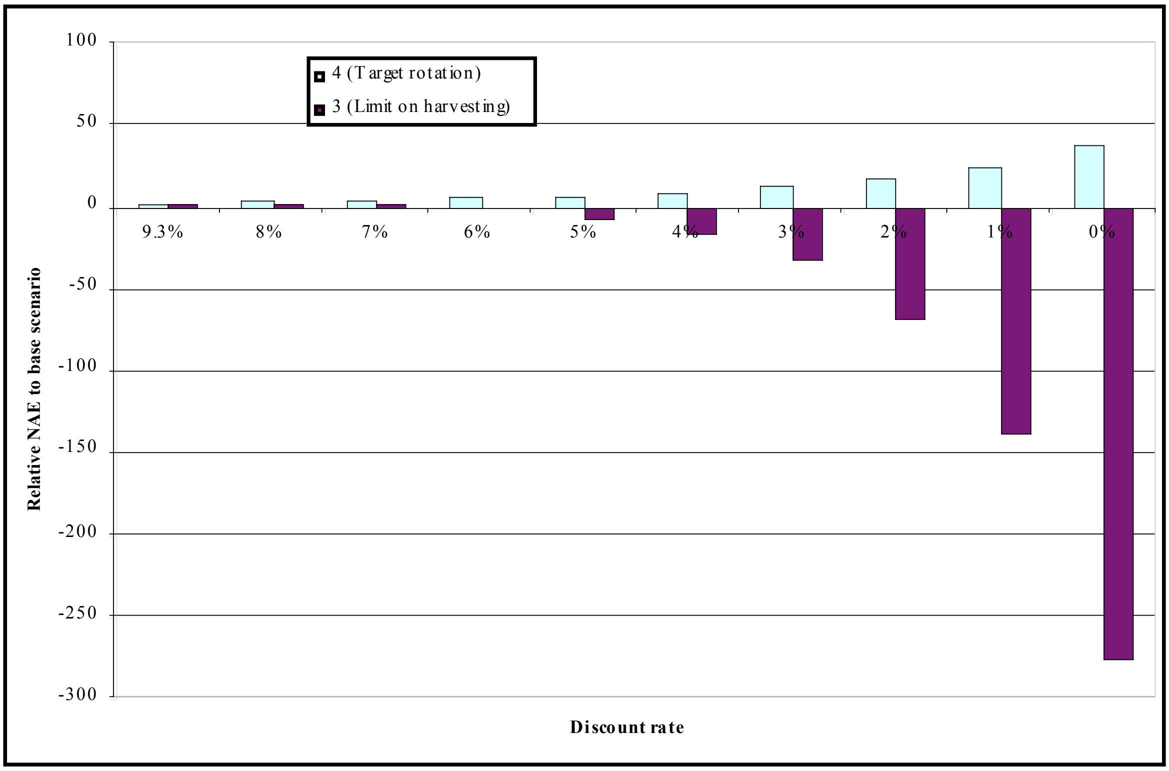

Figure 44. Relative NAE of 'target rotation' (4) and 'limit on harvesting' (3) scenario to base at 0 to 8% discount rate.

For the same scenarios (i.e. 3 and 4), similar results were observed for the carbon balance relative to the baseline scenario, as illustrated in Figure 45 and Figure 46. The differences relative to the baseline scenario did not reach negative levels for lower discount rates, and the balance for both scenarios remained at levels above the base.

The break-even discount rate at which both scenarios had equal values was approximately 2.4%. The trend of each relative balance for both scenarios over different discount rates and for the break-even point are shown in Figure 46.

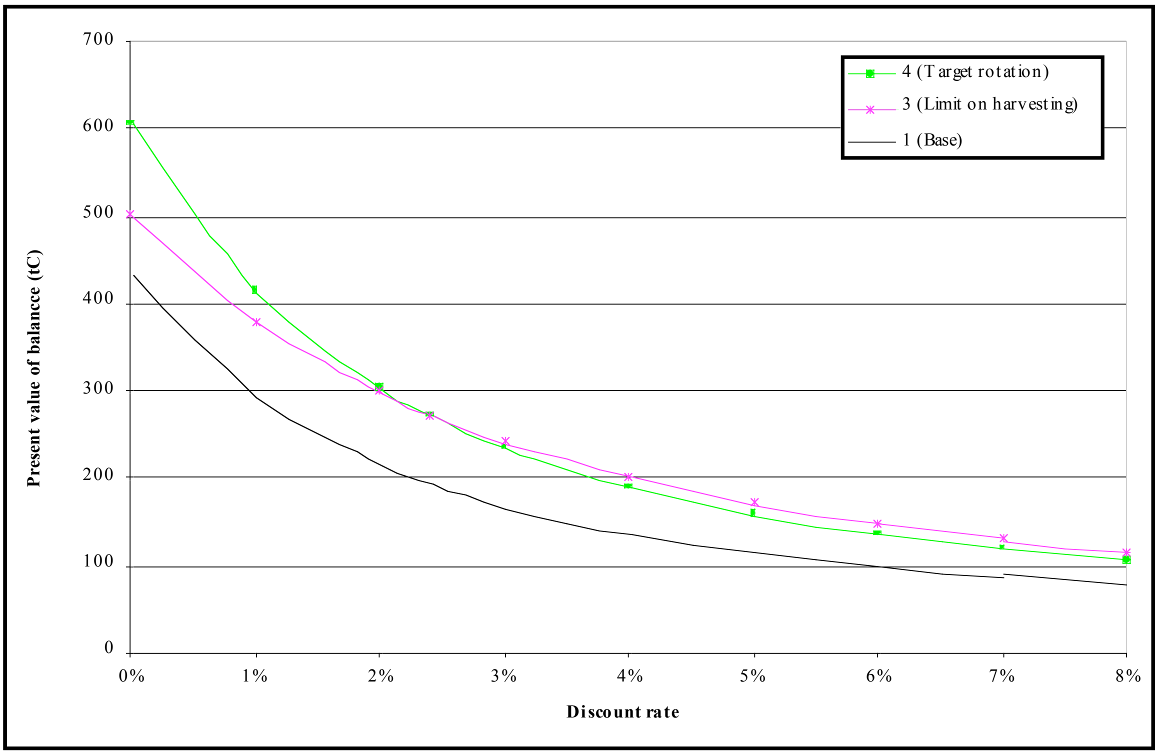

Figure 45. Present value of balance for base scenario, 'limit on harvesting' (3) and 'target rotation' (4) at discount rates from 0% to 8%.

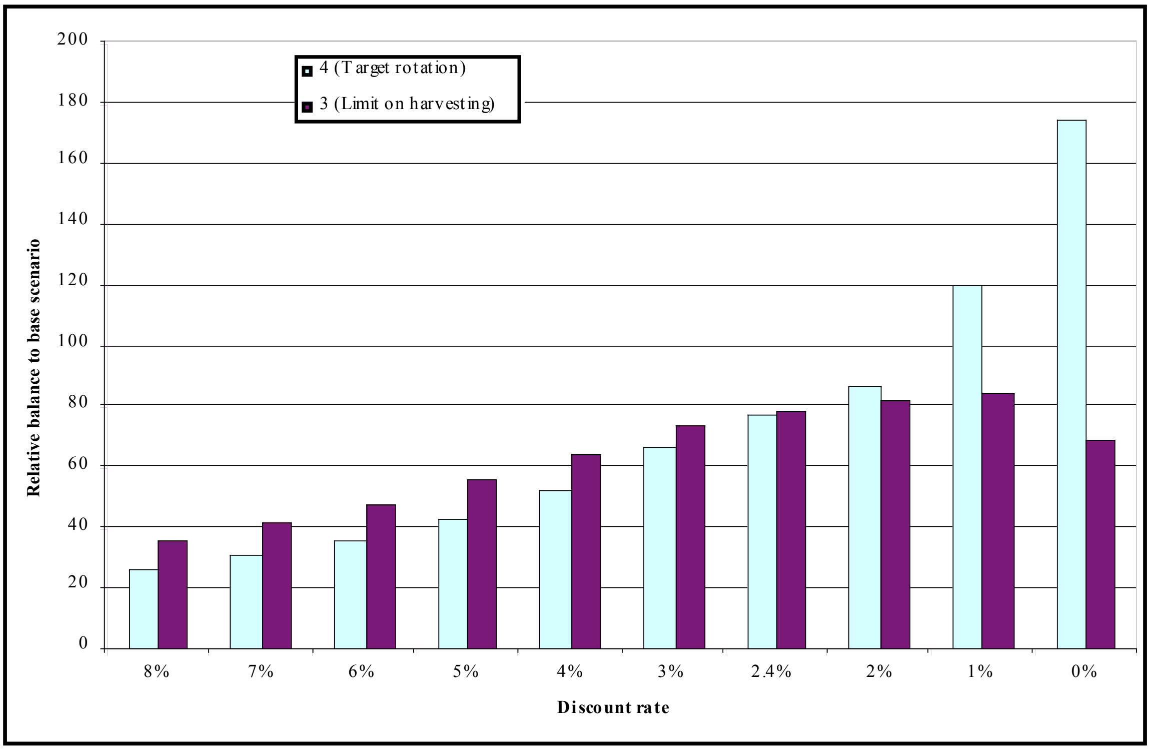

Figure 46. Relative balance of 'target rotation' (4) and 'limit on harvesting' (3) scenario to base for 0 to 8% discount rate.

5.3 Conclusions

- Methodological aspects of the economics of carbon sequestration are under debate and further research is needed.
- NAE, balance, and relative NAE to base, and relative balance to base took on new values with different discount rates. The higher the discount rate the lower the values.
- NAE and balance lead to different ranking of scenarios, i.e when one scenario is better from NAE point of view, implications on the balance may make it less beneficial.
- There were interactions of scenarios' balance to different discount rates that lead to different conclusions if only a small range of discount rate was analysed.
- Deforestation and limit on harvesting had negative effect compare to base scenario when discount rate was low. This is contradictory to results with 8% discount rate.
- If lower discount rates are to be considered, remaining with the base scenario had high NAE and balance than setting a limit on harvesting. In contrast, changing rotation age had higher NAE and balance than base scenario.

CHAPTER 6. General Discussion and Conclusions

The main objective of this study was to analyse the potential of the forest sector as an integrated system to help mitigate climate change, and the impact of different mechanisms on potential new land planting area, management of stands, and the supply, allocation, and demand of wood, and wood products. Therefore, the carbon balance of the national forest estate, forest industry and harvested wood products as an integrated system was analysed in order to identify whether they meet the aim of reducing GHG emissions.

The following sections summarise the topics covered throughout the thesis, the implications of the assumptions, data and models, and the conclusions.

6.1 Summary and Implications of the Assumptions, Data and Models

The topics covered throughout this thesis, and various aspects on which the information available was limited or incomplete are enumerated in this section.

The analysis in Chapter 2 was based on the carbon balance (i.e net atmospheric exchange in the forest minus emissions) of different national forest estate scenarios. The net present value of these scenarios was estimated and the economic viability was assessed. The level of incentives needed in order to increase the return and become economically viable was estimated. The value of carbon unit necessary to meet this level of incentives was estimated. Chapter 3 looked at the energy use, bioenergy and the carbon balance of the forest sector through an analysis of the impact of log allocation and an increase in the use of processing residues for bioenergy. Other benefits of bioenergy such as emissions avoided through fossil fuel substitution and the energy potential were also analysed.

Only forest planted on bareland after 1990 would be eligible under the KP negotiations. In this study, the forest estate modelled did not differentiate plantations pre and post 1990, therefore, the results are indicative only and do not represent forest ‘’sinks’’ eligible for emission trading. Other factors, such as vegetation cover of land before planting, were not included in the estimations, thus the estimates do not represent KP carbon stocks or carbon stock changes.

There are several emissions, that will directly or indirectly have an impact on the carbon balance, that were not included in this study. Soil and transport emissions are examples of these. Inclusion of these emissions on the whole system could affect the results found in the study. If both, soils and transport are a source of emissions, the result of the balance developed is overestimating the positive impact on the atmosphere. The results also heavily rely on the decay rates and lifetime assumed for wood products, as well as conversion factors of products, emission factors, and energy intensity. Moreover, accounting for avoided fossil fuel emissions for energy but not for products; and delaying emissions from in-forest decay but not outside the forest are aspects of accounting that affect the carbon balance results.

Further research and analysis on aspects such as the end use of products and their lifetime, and emissions avoided through harvested wood products substitution, among others, would improve the quality of the results and augment their application for policy analysis and design. If the objective was to be consistent with KP regulations, and to improve the accuracy of the results, further research is needed on an integrated system that includes these regulations.

Other scenarios like forestry versus farming, or wood versus non-wood are beyond the scope of the study and were not analysed. Alternatively, the counterfactual land use situation (i.e. cropping, dairy, etc) could be included, and/or the alternative product emissions could be included, as with bioenergy. It is acknowledged that other scenarios should be taken into consideration for policy design.

An analysis of the land use economics at a regional level was presented in Chapter 4. The question of whether incentives granted to individual projects are needed to encourage land use change to forestry, was investigated. The level of incentive necessary to achieve this change was analysed in economic terms (i.e land expectation value vs land market value). The results of this analysis were compared to the carbon balance at the national level. In Chapter 5 the implications of discount rates on carbon benefits as well as options to address these controversial issues were discussed.

The carbon value examined in this study does not represent the carbon ‘’sink’’ value eligible under the KP. Further development of the integrated system including the KP regulations would improve the results and enable its use for implementation of mechanisms addressing emission reduction. Moreover, the carbon value needed to incentivise new planting is based on the estimated LEV. LEV directly relies on costs, log prices, and the discount rate assumed, thus changes on these values will change the results and the mitigation options to recommend.

An 8% discount rate was used for all present value estimations, whether for net atmospheric exchange, carbon balance and NPV. As was presented in Chapter 5 discounting does have an impact on the results, thus they are indicative only, and if a lower discount rate is used different results would be expected. The NPV results are a consequence of costs and revenues used. These are likely to change, and thus should also be taken as indicative only. The approach to compare LEV to LMV to identify the level of incentives necessary to improve the economic viability of projects is founded on the assumption that forest enterprises are purely based on economic decisions. There are many land use decisions that are not economically rational. The LMV being equal to LEV may be a necessary but not sufficient condition to convert land into forestry. It would also be necessary to analyse and compare LEV for dairy, farm or other land uses vs LEV for forestry.

All results are based on the approach followed to estimate carbon stocks and flows, which are dependent on the growth and yield models used to estimate volumes and carbon. These models determined the MAI of the stands, as well as the responses of the stands to thinning, recoverable volume extracted and residues. The yield tables also affect the LEV through the total recoverable volume extracted from forest that lead to revenues. Revenues change if different yield tables or log types are modelled. Additionally there were assumptions regarding the national forest estate such as areas of forest, replanting and new planting area, the proportion of species, rotation age, and hence the volumes and carbon sustained in the long term. Therefore, the results are only indicative to enable an analysis of the complexity of the whole system. Caution should be taken when interpreting the results.

6.2 Summary and Implications of the Conclusions

The key conclusions on the different topics covered in this study were presented at the end of each chapter. In this section they are summarised and their implications are discussed.

Carbon Balance of the Forest Industry

- **NAE vs Balance**. The ranking of the examined scenarios differs depending on the type of analysis undertaken. The NAE of forest plantations only and the balance of the forest industry as an integrated system should both be analysed before deciding on the most appropriate mitigation options to meet the expected objectives. If the objective is to maximise forest carbon sequestration, the new planting scenarios are the best mitigation options. Increasing the target rotation age does not provide as much benefit as new planting scenarios but is a better option than setting a limit on harvesting. Deforestation should be avoided as it removes a sink and increases emissions.

  If the objective is to maximise the carbon benefits of the entire forest industry new planting scenarios with the same croptypes are the best mitigation option. The limit on harvesting provides less mitigation benefit than increasing the target rotation or the base case. Therefore, there is no incentive to limit the harvesting volume. Deforestation has a negative balance and should be avoided.

  New planting can be seen as a benefit to the atmosphere as it increases forest sinks and reservoirs. However, the new planting of unmanaged hardwoods scenario decreases the carbon balance of the forest industry compared to the base case. Factors such as log allocation and end-use of products affect the carbon balance in such a way that a new planting strategy could result in decreasing the mitigation potential of the industry as a whole. Whether the objective is to maximise forest carbon sequestration or carbon benefits of the entire forest industry, new plantings for long-lived products is the best mitigation option. This is consistent with the IPCC (2006) that reports "*in the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual yield of timber, fibre, or energy from the forest, will generate the largest sustained mitigation benefit*".

- **Net present value (NPV) and additional carbon value.** Only deforestation showed a higher NPV than base. All other scenarios analysed showed a lower NPV. Additional revenues or incentives were needed to increase the returns to an economically viable level. The carbon price necessary to increase the returns of forestry to 8% increases when land value increases. New planting into the same croptypes and avoiding deforestation would be the preferred mitigation option with land values below $2000 /ha (i.e lower additional revenues from carbon were needed). However, for land values above $2000 /ha , new planting with hardwoods will need the lowest carbon value per unit of carbon sequestered (NAE) and thus would be the preferred mitigation option.

  When the carbon balance for the whole industry was valued, avoiding deforestation (on land valued up to $11000/ha) is the cheapest mitigation option to encourage. In land valued above that level, new planting with hardwoods would be the cheapest option.

  Given the assumptions made on costs and revenues, afforestation and/or avoiding deforestation would need incentives. The level of incentives in carbon unit values depends on the value of land and hence, the mitigation options that maximise economic and environmental benefits are site specific. These factors should be taken into consideration while making decisions on policies and mechanisms to mitigate climate change. A national policy ignoring these regional or site specific implications may not achieve the desired outcomes.

Energy Use, Bioenergy and the Carbon Balance of the Forest Sector

- **Sawmill residues for bioenergy**. Bioenergy is not as attractive as using biomass for products in terms of the carbon balance. The higher the processing residues used for bioenergy (rather than being left on site to decay over time), the lower the carbon balance (tC/yr). The benefit of using bioenergy derives from the potential to improve the carbon balance by reducing additional emissions from fossil fuel sources and its potential to generate renewable energy for the sector.
- **Accounting**. The carbon accounting methodology and the allocation of emissions have an effect on the carbon balance results. Using conservative accounting for export logs (i.e allocating responsibilities to the producer country and instant emissions) leads to a positive relative balance if processing occurs onshore. Some emissions such as harvested wood products and residues emissions are delayed, and hence a better

balance is achieved for the whole industry. HWP accounting under the Kyoto Protocol negotiations has been under debate, but no agreement has been reached. To whom, when and where emissions from export wood products are allocated should be taken into consideration for policy negotiations.

- **Energy potential**. The sawmill processing sector has the potential to produce more than enough energy from their residues to meet their needs. However, there are barriers to overcome in order to increase bioenergy use.
- **Barriers to bioenergy uptake**. The main barriers identified to bioenergy uptake were costs, image and knowledge about technology, handling and workers. Lack of knowledge can be overcome by increasing the promotion of its use and benefits, in order to give signals to all sectors and enhance capabilities in all parts of the bioenergy chain.

Land Use Economics

- **Negative Land Expectation Value (LEV)**. The LEV (at 8% discount rate) for a radiata pine croptype was negative except for low transport distances and some regions in the North Island (i.e Gisborne, Southern North Island, Central North Island and Hawkes Bay). The whole South Island had negative LEV. This is consistent with the national forest estate level analysis in which new planting showed negative NPV. Therefore, incentives to improve the profitability of new plantings are needed.
- **Land Market Value vs Land Expectation Value**. The LMV was higher than LEV; thus additional revenues are needed to make conversion of land to forestry economically viable. The lowest level of incentives that would be needed (i.e values that equate LMV and LEV) based on the assumption of 50 km distance to destination site and $\$18/m^3$ for harvesting costs was $580/ ha. The highest value recorded under the same assumptions was $5600/ha.
- **Carbon unit value at land values reported**. Given the reported market value of land, the lowest carbon unit value to make a change on the economics of mitigation options through land use management (i.e avoiding deforestation) was 13.2 $/tC. The highest carbon unit value recorded was $70.4/tC for new planting with hardwoods.

Under the assumptions of costs and revenues made in this study, whether at a national or project level, new planting has lower returns than 8% in most areas of the country.

Incentives would be required to avoid deforestation or increase the new planting rates as preferred mitigation options, as well as other management options that would lead to a benefit to the atmosphere and help meeting the UNFCCC commitments, incentives would be required.

Carbon Benefits and Discounting

- **Effect of lower discount rate**. The discount rate has an effect on the short and long term discounted level of net atmospheric exchange and carbon balance. The higher the discount rate the lower the values of discounted NAE, balance, relative NAE to base, and relative balance to base.
- **Interactions between scenarios and discount rate**. There were interactions of relative balance between scenarios and for different discount rates to lead to different conclusions if only a small range of discount rate are analysed.

6.3 Overall Conclusions

The main objective of the thesis was to analyse the potential of the forest sector as an integrated system to help mitigate climate change, and the impact of different mechanisms on potential new land planting area, management of stands, and the supply, allocation, and demand of wood, and wood products

The carbon balance of forest plantations (i.e. *Pinus radiata*, *Pseudotsuga menziessii,* hardwoods and other softwoods in New Zealand) and the forest industry as an integrated system (i.e. carbon net atmospheric exchange of forest plantations, and emissions from wood processing sector and wood products) was estimated. The results indicate that broader consideration than forest alone is needed to analyse the complexity of the issues affecting the impact of forests on the atmosphere and to develop policies addressing climate change and its mitigation. The carbon balance of forest plantations and the forest industry as an integrated system should be analysed for deciding the most appropriate mitigation option.

The level of incentive necessary to have an impact on new planting area and increase sequestration, reduce emissions from deforestation, and to improve the economic returns of forestry projects were determined. The national level carbon balance was the main indicator of the impacts. Under the assumptions made in this study, the NPV of forest projects were negative, and hence, new planting may not occur if economic factors are the main drivers for land use change to forestry. The LEV for most regions in New Zealand were lower than the land market value, thus forestry would not be an economic option for these land. Subsequently, additional revenues or incentives are needed to increase the economic return to an economically viable level (i.e above 8%). The level of incentives in carbon unit value is site specific, therefore, if carbon value is believed to be one of these incentives, national policies should take these issues into account to achieve the desired outcomes.

Mitigation options through land use management, forest industry and bioenergy aimed at reducing GHG emissions for the short and long term were identified. The best mitigation options analysed for maximising the carbon sequestration benefits were all new planting scenarios. However, to maximise the carbon benefits of the entire forest industry, new planting scenarios with the same croptypes were the best options. The limit on harvesting provides less mitigation benefit than increasing the target rotation or the base case and deforestation has negative balance thus should be avoided. The effect of changing log allocation was small compared to the forestry options. However, factors such as decay rate of HWP would affect these results. Bioenergy is not as attractive as using biomass for long lived products in terms of the carbon balance. It would be beneficial not to use residues and leave them on site to decay overtime, and hence delay emissions rather than using them for bioenergy. Avoided emissions through bioenergy use improve the balance results for bioenergy as mitigation option. There are other implications and benefits of using an available renewable resource that can be used rather than being wasted instead.

The potential of the forestry sector to increase the use of woody biomass (residues from wood processing) for bioenergy and the impact of emissions avoided on the carbon balance when biomass substitute fossil fuel was assessed. There is potential energy that can be produced from processing residues, whether to substitute fossil fuels or to meet future energy demand instead of using the same energy source currently being used. Using 100% of processing residues generated by the sawmill sector would be enough to meet their energy demand and there would also be an excess of energy to commercialise. Under these circumstances, the sawmill sector would be self-sufficient, a net exporter of energy, potentially avoid emissions from fossil fuel, reduce costs from waste disposal to landfill, and reduce risks and uncertainty of energy supply. However, there is a range of significant barriers preventing more active deployment of bioenergy into the New Zealand market. The forest industry and the country would derive benefit from bioenergy if these barriers were overcome.

The use of discount rate on the economic analysis of carbon benefits as an environmental and market value of forest was investigated. Discount rate has an impact on short and long term results of carbon balance and net atmospheric exchange. If only one or a small range of discount rate is used on mitigation option analysis, different conclusions can be drawn. The definition of appropriate discount rates when carbon is considered as an environmental benefit from forest is important to be considered by the Government when long-term policies to mitigate climate change and forest industry sustainability are being discussed.

The New Zealand forest sector as a whole has the potential to develop in a sustainable way and mitigate climate change. Broader consideration than forest alone is needed to value these benefits. New plantings with intensively managed regimes for long-lived products, maximum use of residues being currently left to decay (whether for added value products or energy generation to substitute fossil fuels) are the best options to encourage and maximise the potential benefits of the sector to the atmosphere and climate change mitigation. There are several factors that do not help to achieve these objectives, but economic factors are the most important ones, therefore, incentives are needed. The integration of carbon value in these economic instruments is one option that can be taken into consideration to capitalize on the development of the carbon market. In view of the fact that, the timing of emissions, sequestration, emissions avoided and payments from these economic instruments strongly affect the present and future benefit to the atmosphere, an adequate discount rate to value these benefits must be carefully chosen.

Appendix I. Total recoverable volume (m^3) and mean annual increment (m^3/yr) for the seven croptypes included in the carbon balance analyse.

Croptypes	**1**		**2**		**3**		**4**		**5**		**6**		**7**	
Age	TRV	**MAI**	TRV	**MAI**	TRV	**MAI**	TRV	**MAI**	TRV	**MAI**	TRV	**MAI**	TRV	**MAI**
10	52.6	5.3	108	10.8	92.7	9.3	107.9	10.8	90.3	9.0	0	0.0	40.5	4.1
11	70.5	6.4	139.4	12.7	125.7	11.4	139.6	12.7	125.4	11.4	0	0.0	57.3	5.2
12	94.2	7.9	56.7	4.7	161.6	13.5	180.1	15.0	154.7	12.9	1.2	0.1	75.5	6.3
13	116.9	9.0	74.7	5.7	196.5	15.1	210.7	16.2	182.5	14.0	8.6	0.7	94	7.2
14	140.1	10.0	95.7	6.8	224.1	16.0	91.9	6.6	211.6	15.1	22.7	1.6	41.5	3.0
15	165.1	11.0	117.1	7.8	252.5	16.8	110.7	7.4	246	16.4	28.1	1.9	53	3.5
16	191	11.9	141.8	8.9	282.6	17.7	131.9	8.2	278.7	17.4	39.2	2.5	65.6	4.1
17	216.6	12.7	164.7	9.7	312.3	18.4	154.3	9.1	307.7	18.1	52.1	3.1	78.9	4.6
18	241.8	13.4	187.9	10.4	339.6	18.9	176.6	9.8	336.8	18.7	65.6	3.6	93.9	5.2
19	269.3	14.2	214.3	11.3	371.7	19.6	202	10.6	371.4	19.5	81.1	4.3	109.5	5.8
20	297.2	14.9	239.3	12.0	402.3	20.1	227.7	11.4	399.5	20.0	97.3	4.9	125.6	6.3
21	322.8	15.4	262.8	12.5	432.9	20.6	251.5	12.0	427.2	20.3	116.5	5.5	142.9	6.8
22	350.5	15.9	288.6	13.1	464.1	21.1	277.5	12.6	453.4	20.6	132.7	6.0	159.4	7.2
23	379.6	16.5	316.4	13.8	495.5	21.5	303.4	13.2	477.4	20.8	149.9	6.5	176	7.7
24	406.4	16.9	341.1	14.2	524.7	21.9	328.2	13.7	502.2	20.9	168.5	7.0	192.9	8.0
25	431.4	17.3	364.6	14.6	552.1	22.1	352	14.1	528.7	21.1	191.1	7.6	211.1	8.4
26	456.8	17.6	388.8	15.0	579.3	22.3	375.7	14.5	553.4	21.3	211.9	8.2	230.1	8.9
27	481.6	17.8	413.1	15.3	606	22.4	399.7	14.8	577.2	**21.4**	232.1	8.6	247.8	9.2
28	507.9	18.1	437.6	15.6	635.7	22.7	424.4	15.2	598.2	21.4	252.6	9.0	265.7	9.5
29	534.4	18.4	463	16.0	661.9	22.8	449.6	15.5	618	21.3	275.5	9.5	284.5	9.8
30	560.2	18.7	487.9	16.3	689.9	23.0	475.4	15.8	637.5	21.3	298.8	10.0	303.5	10.1
31	584.9	18.9	511.7	16.5	716.6	23.1	497.9	16.1	657.6	21.2	324.5	10.5	322.4	10.4
32	609.7	19.1	535.4	16.7	741.4	**23.2**	522.1	16.3	674.9	21.1	349.2	10.9	340.7	10.6
33	632.5	19.2	557.7	16.9	766.5	23.2	545	16.5	691.4	21.0	374.4	11.3	358.2	10.9
34	656.3	19.3	580.8	17.1	791.1	23.3	567.2	16.7	706.9	20.8	398.3	11.7	375.4	11.0
35	679.5	19.4	602.5	17.2	812.7	23.2	590.1	16.9	725.4	20.7	423.8	12.1	392.9	11.2
36	701.2	19.5	623.9	17.3	836.8	23.2	610.5	17.0	742.1	20.6	451.4	12.5	410.9	11.4
37	722.1	19.5	644.1	17.4	857.9	23.2	631.4	17.1	756.9	20.5	477.7	12.9	428.4	11.6
38	742.7	19.5	664.1	17.5	879	23.1	651	17.1	770.9	20.3	503.8	13.3	447.1	11.8
39	762.5	**19.6**	684.3	17.5	899.3	23.1	671.6	17.2	784.3	20.1	529.3	13.6	465	11.9
40	782.7	19.6	704.4	17.6	918.7	23.0	690.7	17.3	801.8	20.0	555.5	13.9	483.2	12.1
41	802.5	19.6	722.3	17.6	938.8	22.9	710.4	17.3	814.8	19.9	581.3	14.2	499.7	12.2
42	821.5	19.6	742.4	**17.7**	959	22.8	729.5	17.4	826.8	19.7	607.2	14.5	516.9	12.3
43	838.7	19.5	760.2	17.7	977.9	22.7	748	17.4	838	19.5	635.9	14.8	534.6	12.4
44	858.1	19.5	780.3	17.7	994.6	22.6	767.9	**17.5**	848.5	19.3	664.3	15.1	550.8	12.5
45	877.3	19.5	798.2	17.7	1013.6	22.5	785.2	17.4	858.6	19.1	692.8	15.4	567.5	12.6
46	893.9	19.4	815	17.7	1031.2	22.4	803	17.5	868.1	18.9	720.4	15.7	583.9	12.7
47	911.2	19.4	832.2	17.7	1046.5	22.3	820.3	17.5	877.1	18.7	746.8	15.9	599.5	12.8
48	928	19.3	847.6	17.7	1062.6	22.1	835.8	17.4	885.9	18.5	773.7	16.1	614.4	12.8
49	943.1	19.2	863.7	17.6	1078.9	22.0	851.6	17.4	897.7	18.3	802.1	16.4	630.6	**12.9**
50	958.8	19.2	878.2	17.6	1093.3	21.9	866.4	17.3	905.6	18.1	830.4	16.6	645.7	12.9

Appendix II. LEV for each wood supply region under different assumptions on transport distances and harvesting costs.

	Relative LEV (25 transp cost)								Relative LEV (18 transp cost)							
Transport distances	**50**		**100**		**150**		**200**		**50**		**100**		**150**		**200**	
Land type	**Hill**	**Hard hill**	**Hill**	**Hard hill**	**Hill**	**Hard hill**	**Hill**	**Hard hill**	**Hill**	**Hard hill**	**Hill**	**Hard hill**	**Hill**	**Hard hill**	**Hill**	**Hard hill**
Northland	5475	4356	5816	4697	6157	5038	6498	5379	5041	3922	5382	4263	5723	4604	6064	4945
Auckland	5381	2854	5707	3180	6033	3505	6359	3831	4966	2439	5292	2765	5618	3091	5944	3417
Central North Island	4728	2200	5089	2561	5450	2922	5811	3283	4268	1741	4629	2102	4990	2463	5351	2824
Gisborne	4536	3514	4940	3918	5343	4321	5747	4725	4023	3001	4426	3404	4830	3808	5233	4211
Hawkes Bay	3263	1791	3623	2151	3983	2511	4343	2870	2805	1333	3165	1693	3525	2053	3885	2412
Southern North Island	3877	1217	4272	1613	4668	2008	5064	2404	3373	713	3769	1109	4164	1505	4560	1901
Transport distances	**50**		**100**		**150**		**200**		**50**		**100**		**150**		**200**	
Land type	**Hill**	**Finishing breeding**	**Hill**	**Finishing breeding**	**Hill**	**Finishing breeding**	**Hill**	**Finishing breeding**	**Hill**	**Finishing breeding**	**Hill**	**Finishing breeding**	**Hill**	**Finishing breeding**	**Hill**	**Finishing breeding**
Nelson and Marlborough	1817		2113		2410		2707		1439	572	1736	869	2032	1165	2329	1462
West Coast																
Canterbury	2753	5872	2967	6086	3182	6300	3396	6515	2480	5599	2695	5814	2909	6028	3123	6242
Otago and Southland	3077	4007	3359	4289	3641	4571	3924	4853	2718	3648	3000	3930	3282	4212	3565	4494

Appendix III. North Island Wood Supply Regions Showing Territorial Authority Boundaries. Source: (MAF 2004)

Appendix IV. South Island Wood Supply Regions Showing Territorial Authority Boundaries

Appendix V. Energy potential (PJ) of sawmill residues and processing plants energy demand (PJ) for the 'base' scenario.

Year	Energy potential (PJ)				Energy demand (PJ)						
	Base	20% PR	50% PR	100% PR	Sawmill	Chemical Pulp	Mechanical Pulp	Panels			TOTAL
								Veneer	Particleboard	Fibreboard	
2001	0.1	0.3	0.7	1.3	15.7	67.9	7.6	1.9	0.1	1.8	95.1
2002	0.3	0.5	1.3	2.6	15.5	72.3	8.2	1.9	0.1	2.0	100.1
2003	0.3	0.6	1.5	3.0	15.8	71.1	8.2	2.1	0.1	2.0	99.3
2004	0.6	1.3	3.2	6.4	16.4	76.7	9.4	2.2	0.3	2.2	107.1
2005	1.0	2.0	4.9	9.9	16.9	83.4	10.7	2.3	0.5	2.4	116.1
2006	1.4	2.8	6.9	13.9	18.0	86.7	11.7	2.5	0.7	2.5	122.1
2007	2.0	4.0	10.1	20.2	21.7	81.9	11.5	2.9	0.8	2.5	121.2
2008	2.5	4.9	12.3	24.6	22.8	84.9	12.1	3.1	0.9	2.7	126.5
2009	2.7	5.4	13.4	26.8	23.2	87.7	12.6	3.2	1.1	2.8	130.5
2010	2.7	5.5	13.7	27.5	23.7	85.1	12.2	3.3	1.0	2.7	128.1
2011	3.0	6.0	14.9	29.8	25.7	75.0	11.0	3.7	0.9	2.3	118.6
2012	2.7	5.4	13.5	27.0	23.3	87.0	12.4	3.1	1.1	2.8	129.7
2013	2.7	5.5	13.6	27.3	23.5	86.1	12.3	3.2	1.0	2.8	128.9
2014	2.7	5.5	13.7	27.3	23.6	85.7	12.3	3.2	1.0	2.8	128.5
2015	2.7	5.3	13.3	26.5	22.9	89.0	12.7	3.1	1.1	2.9	131.6
2016	2.8	5.6	13.9	27.8	24.0	83.6	12.0	3.3	1.0	2.7	126.5
2017	2.7	5.4	13.4	26.9	23.2	87.7	12.5	3.1	1.1	2.8	130.4
2018	2.8	5.5	13.8	27.6	23.8	84.7	12.2	3.3	1.0	2.7	127.7
2019	2.6	5.3	13.2	26.4	22.8	89.6	12.8	3.1	1.1	2.9	132.2
2020	2.6	5.3	13.1	26.3	22.7	90.4	12.9	3.0	1.1	3.0	133.0
2021	2.6	5.2	13.1	26.2	22.6	90.7	12.9	3.0	1.1	3.0	133.3
2022	2.6	5.2	13.1	26.2	22.6	90.5	12.9	3.1	1.1	3.0	133.1
2023	2.6	5.2	13.1	26.1	22.6	90.4	12.9	3.0	1.1	3.0	133.0
2024	2.8	5.6	14.0	28.1	24.2	82.3	11.9	3.4	1.0	2.7	125.4
2025	2.9	5.7	14.4	28.7	24.8	79.7	11.6	3.5	1.0	2.6	123.1
2026	2.7	5.5	13.7	27.4	23.6	85.5	12.3	3.3	1.0	2.8	128.5
2027	2.8	5.6	14.0	28.0	24.2	83.3	12.0	3.4	1.0	2.7	126.5
2028	2.7	5.3	13.3	26.6	22.9	88.6	12.7	3.1	1.1	2.9	131.2
2029	2.7	5.4	13.4	26.8	23.1	87.9	12.6	3.1	1.1	2.8	130.6
2030	2.7	5.3	13.3	26.7	23.0	88.4	12.6	3.1	1.1	2.8	131.0
2031	2.7	5.3	13.3	26.7	23.0	88.3	12.6	3.1	1.1	2.8	130.9
2032	2.7	5.4	13.5	27.1	23.4	86.8	12.4	3.2	1.0	2.8	129.5
2033	2.7	5.4	13.5	26.9	23.2	87.5	12.5	3.2	1.1	2.8	130.2
2034	2.8	5.6	13.9	27.9	23.9	85.1	12.2	3.2	1.0	2.7	128.2
2035	2.8	5.5	13.8	27.6	23.6	86.3	12.4	3.2	1.0	2.8	129.3
2036	2.8	5.6	13.9	27.8	23.8	85.4	12.3	3.2	1.0	2.7	128.5
2037	2.7	5.4	13.5	27.1	23.2	88.2	12.6	3.1	1.1	2.8	131.0
2038	2.7	5.4	13.4	26.8	23.0	89.1	12.7	3.1	1.1	2.9	131.9
2039	2.7	5.4	13.5	26.9	23.1	88.9	12.7	3.1	1.1	2.9	131.7
2040	2.7	5.4	13.4	26.8	22.9	89.5	12.8	3.0	1.1	2.9	132.3
2041	2.6	5.3	13.1	26.3	22.5	91.6	13.0	3.0	1.1	3.0	134.3
2042	2.7	5.4	13.5	27.1	23.2	88.5	12.6	3.1	1.1	2.9	131.4
2043	2.7	5.4	13.5	27.0	23.1	88.9	12.7	3.1	1.1	2.9	131.8
2044	2.7	5.4	13.6	27.1	23.2	88.4	12.6	3.1	1.1	2.9	131.4
2045	3.0	6.0	14.9	29.9	25.6	77.0	11.2	3.6	0.9	2.4	120.8
2046	2.9	5.8	14.4	28.8	24.7	81.7	11.8	3.4	1.0	2.6	125.2
2047	2.7	5.3	13.3	26.6	22.8	90.0	12.8	3.0	1.1	2.9	132.8
2048	2.7	5.4	13.5	27.1	23.2	88.1	12.6	3.1	1.1	2.9	131.0
2049	2.7	5.5	13.7	27.4	23.5	86.7	12.4	3.2	1.1	2.8	129.6
2050	2.7	5.3	13.4	26.7	22.9	89.9	12.8	3.0	1.1	2.9	132.7
2051	2.7	5.3	13.4	26.7	22.9	90.0	12.8	3.0	1.1	2.9	132.8
2052	2.7	5.4	13.6	27.2	23.3	88.3	12.6	3.1	1.1	2.9	131.2
2053	2.7	5.5	13.7	27.3	23.4	87.5	12.5	3.1	1.1	2.8	130.5
2054	2.8	5.5	13.8	27.6	23.7	85.9	12.3	3.2	1.1	2.8	129.0
2055	2.7	5.4	13.4	26.8	23.0	89.3	12.7	3.0	1.1	2.9	132.1
2056	2.7	5.4	13.5	27.0	23.1	88.8	12.7	3.1	1.1	2.9	131.6
2057	2.7	5.5	13.7	27.5	23.6	86.8	12.4	3.2	1.1	2.8	129.8
2058	2.9	5.8	14.6	29.1	25.0	79.8	11.6	3.5	1.0	2.5	123.3
2059	3.0	6.0	15.1	30.1	25.8	75.6	11.1	3.7	0.9	2.4	119.4
2060	2.9	5.7	14.3	28.6	24.5	82.8	11.9	3.4	1.0	2.7	126.3
2061	2.6	5.3	13.2	26.5	22.7	90.7	12.9	3.0	1.1	3.0	133.3
2062	2.8	5.6	13.9	27.9	23.9	85.4	12.3	3.2	1.0	2.8	128.6
2063	2.6	5.3	13.2	26.3	22.6	91.2	13.0	3.0	1.1	3.0	133.8
2064	2.7	5.3	13.3	26.6	22.8	90.4	12.9	3.0	1.1	2.9	133.1
2065	2.6	5.3	13.1	26.3	22.5	91.5	13.0	2.9	1.1	3.0	134.1
2066	2.6	5.3	13.2	26.3	22.5	91.4	13.0	2.9	1.1	3.0	134.0
2067	2.7	5.4	13.4	26.8	23.0	89.3	12.7	3.0	1.1	2.9	132.1

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